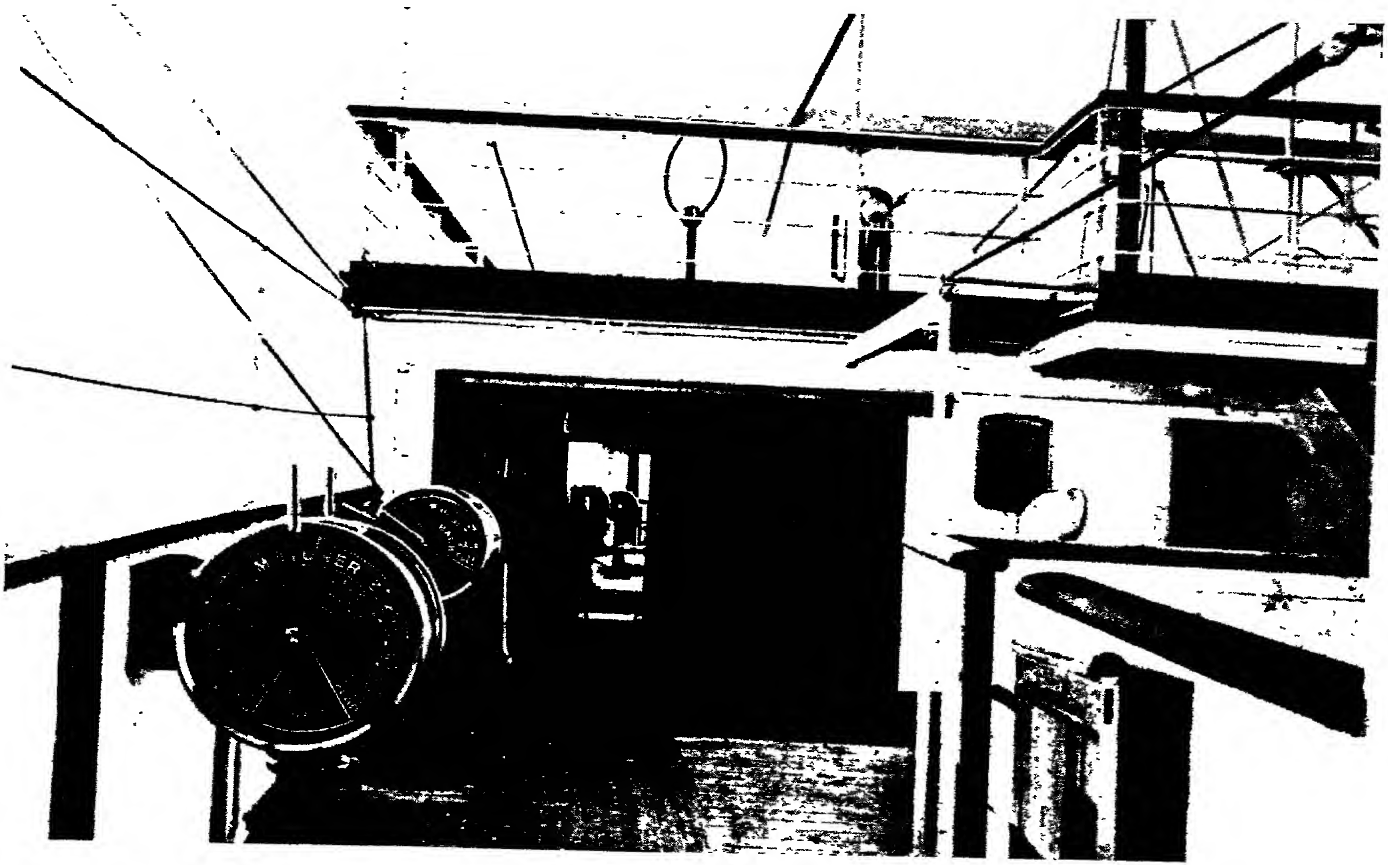
NAVIGATIONAL WIRELESS



[*Photo. by Bedford Lemere & Co.*

Direction finder fitted on bridge of M.S. "Gripsholm".

Frontispiece

NAVIGATIONAL WIRELESS

BY

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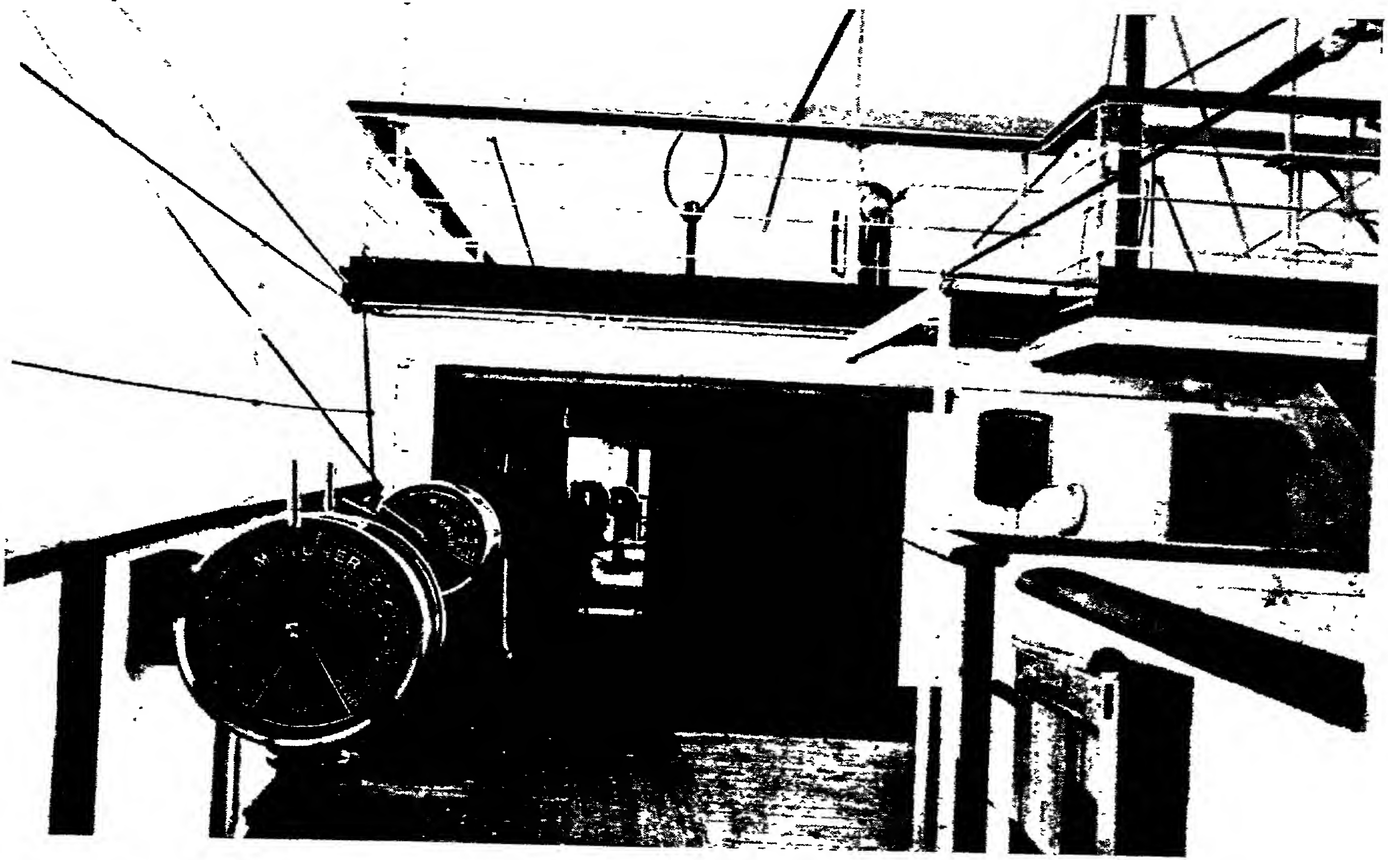

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Direction finder fitted on bridge of M.S. "Gripsholm".

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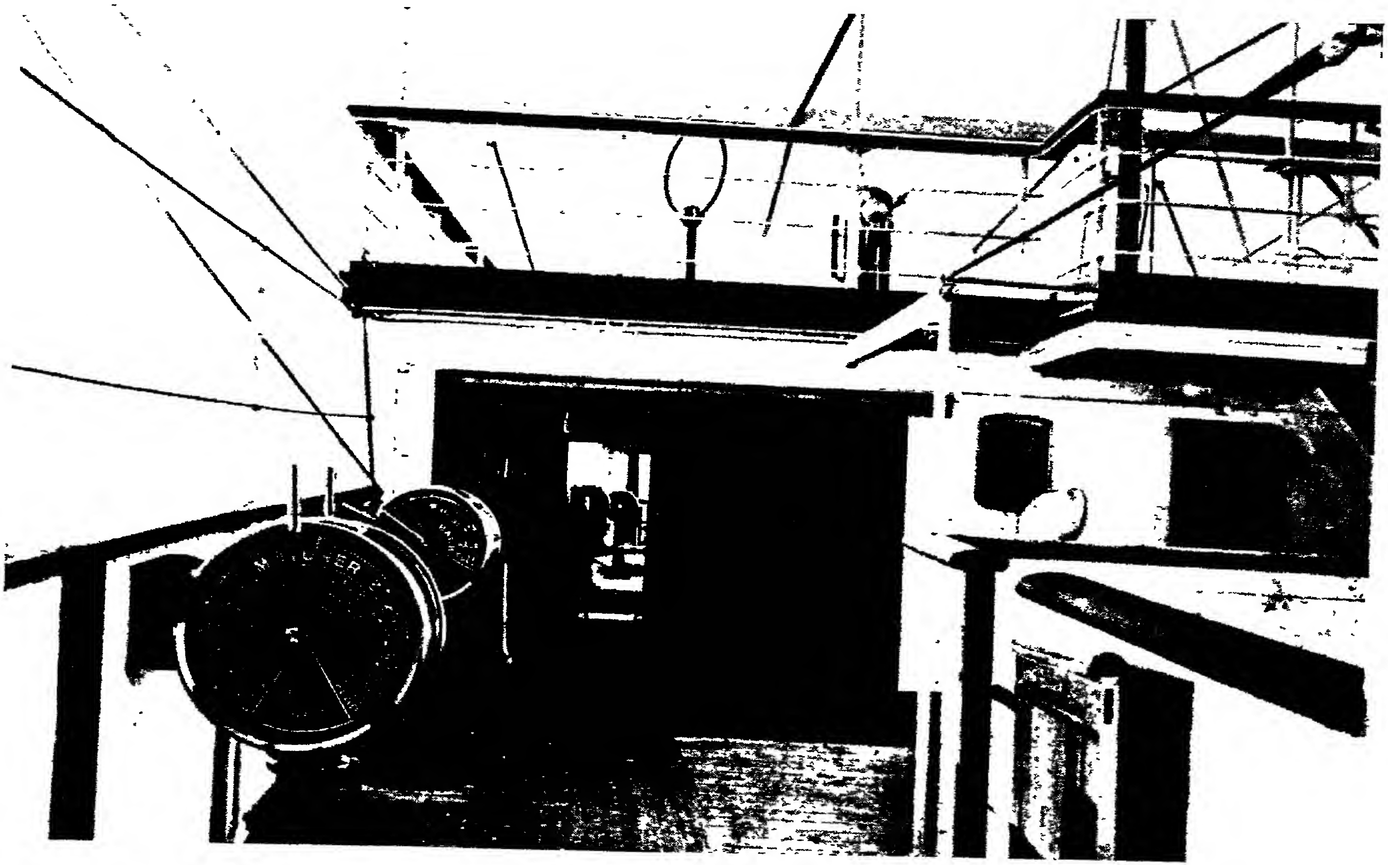
PREFACE.

Some three years ago a single-frame direction-finding apparatus was placed on the British market for the first time. No book in the English language dealing with direction finding by means of a single frame existed at that date, and the need for such a book has been felt ever since. The present book is an attempt to fill this want. The vexed question of whether a D.F. instrument should be worked by a W/T operator or by a navigator is still an open one. Hitherto, unfortunately, there has been a great lack of co-ordination between the two branches, but it is now realised that a close liaison between them is essential for the successful working of D.F. installations. Usually the W/T operator, with a little instruction, was quite capable of taking bearings, but he was not always able to apply them himself or even to understand their application. On the other hand, the navigator, although perfectly able to apply the bearings given to him, had little faith in their accuracy, owing to his lack of electrical knowledge. The object of this book is to link up these two branches so that each has a good working knowledge of what the other is doing. The general electrical principles are very simple, and only that is included which is considered indispensable to procure a working knowledge of D.F. installations. The navigational portion, although no doubt very elementary to the navigator,



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SYNOPSIS OF CONTENTS.

CHAPTER I.

General Electricity.

CHAPTER II.

Valves—Screening.

CHAPTER III.

Principles of Direction Finding.

CHAPTER IV.

Résumé of Direction Finding.

CHAPTER V.

Installation of a Single-frame Aerial on a Ship.

CHAPTER VI.

The Deflection of Wireless Bearings due to the Ship's Metal Mass.

CHAPTER X.

OTHER EFFECTS ON BEARINGS.

CHAPTER XI.

BEACON STATIONS, SOUND SIGNALLING, AND ECHO SOUNDING DEVICES.

APPENDIX I.

APPENDIX II.

APPENDIX III.

APPENDIX IV.

APPENDIX V.

CHAPTER I.

GENERAL ELECTRICITY.

Matter.—The modern conception of matter is that all solids, liquids, or gases can be divided into *molecules*, which in turn can be sub-divided into *atoms*. These atoms are usually looked upon as the smallest portion of a substance which can take part in a chemical action, e.g. 2 atoms of hydrogen (H) and 1 atom of oxygen (O) combine to give 1 molecule of water (H_2O).

These atoms, moreover, are considered to consist of a *positive nucleus* around which there are *negative electrons*. The total negative charges of the various electrons in the atom equal the total positive charge of the positive nucleus. Thus, under normal conditions there is a state of equilibrium. The medium over which these charges act is the *ether*.

Now imagine that a neutral atom is in some way disturbed, so that one electron is taken from it. Then there remains a body which has a surplus of positive charge. This is usually known as a *positive ion*. There remains the separate electron with its negative charge. Owing to the enormous difference in mass between the negative electron (about 1/1800 of a hydrogen atom) and a neutral atom, a mass attraction can be imagined between these two bodies. This would produce a resultant body which has a surplus negative electron and is called a *negative ion*.

To summarise—matter is presumed to consist of a medium called "ether," and bodies which we term "atoms," "electrons," and "ions."

The atom is neutral in charge.

The electron is negatively charged.

An atom plus one or more electrons becomes a body with a surplus negative charge, and is called a "negative ion."

An atom minus one or more electrons is positive in charge and is called "a positive ion."

If a body is changed from its normal condition, that is, of neutral atoms, to a condition of ions (positive or negative) and electrons, then this body is said to be "ionised." For example, if a high-voltage discharge is passed through a gas there occurs an entire change in the condition of that gas. It changes from the condition of neutral atoms to that of positive and negative ions and electrons, and the gas is said to be "ionised."

There is a large number of ionising agents. For instance, an ordinary gas flame in air will produce sufficient ions to discharge a charged electroscope.

Any electric discharge is associated with ionisation.

Any electrolysis is associated with ionisation.

Radioactive substances, e.g. radium or thorium, are ionising agents; "gamma" rays from the sun produce ionisation in the upper atmosphere (see "Night Effect," Chap. X.).

Current of Electricity.—All elements, whether silver, copper, mercury vapour, hydrogen gas, or any other substance, consist of negative electrons in motion around a positive nucleus in an ether medium. The velocity of movement of these electrons is dependent upon the temperature, and the amplitude of the movement depends on the "length of free path," or, to put it more simply, on whether the material is a solid, a liquid, or a gas.

The normal movement of the electrons in the atom does not produce any strain in the ether which can be detected by any known method. Suppose, however, that a general drift of these electrons occurs in one direction in the substance, then conditions exist which are commonly called "an electric current." This has its associated ether strains which can be detected as *lines of force.*

Now each electron carries with it a definite charge, which is $\frac{1 \cdot 57}{10^{19}}$ coulombs. (A coulomb is the unit of quantity of electricity.)

Thus, if we can cause a drift of $\frac{10^{19}}{1 \cdot 57}$ electrons per sec. we would produce a charge of $\frac{10^{19}}{1 \cdot 57} \times \frac{1 \cdot 57}{10^{19}} = 1$ coulomb.

In other words, we would produce a current of 1 ampere through the conductor.

The *legal* definition of an ampere is that steady current which will deposit 0·001118 gram of silver per second on a platinum cathode immersed in a 15 per cent. solution of silver nitrate, the anode being of silver.

Voltage.—If a positively charged body (i.e. one with a deficiency of negative electrons) and a negatively charged body (i.e. one with a surplus of negative electrons) exist at the same time, ether strains will exist between these bodies. The amount of ether strain is called the *pressure* or *potential difference* or *potential* between the bodies. It is measured in *volts*.

Provided the strain were such that 1 ampere would pass through a conductor of a resistance of 1 ohm, then the pressure would be 1 volt. The voltage is usually called the E.M.F. (or *electromotive force*).

Resistance.—Imagine an ether strain in any substance. The resultant movement of the electrons in the substance will depend upon—

(*a*) Nature of the substance.
(*b*) Length of the substance.
(*c*) Area of cross-section of the substance.

For a given ether strain there will be a different movement of the electrons in, say, copper and rubber. It will require a smaller ether strain or pressure (voltage) to cause a flow of electrons through a metal than through a substance like rubber, porcelain, or mica. Substances requiring a small ether strain (voltage) for a definite movement of electrons (current) are called *conductors*, while substances requiring a very high ether strain for a movement of electrons through them are called *insulators*. The terms " conductor " and " insulator " are only relative, and define roughly the ease with which electrons can be caused to drift through the body.

The practical unit of resistance is the *Ohm*, and is defined as the resistance offered to an unvarying current by a column of mercury 106·3 cms. long and of constant cross-section equal to 1 square millimetre, its temperature being at 0° Centigrade.

A Simple Circuit is such as shown in Fig. 1.

It comprises a source of E.M.F., such as a battery, the

voltage of which is measured by a voltmeter V connected directly across it. The source is connected by metal conductors to the resistance R, and the resultant current through the circuit is indicated by the ammeter A, which is connected directly in the circuit.

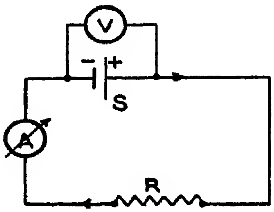

FIG. 1.

There always exists a definite relation between the E.M.F. (e), the resistance (R), and the current (i) flowing through the circuit. This relation is

$$i \text{ (in amperes)} = \frac{e \text{ (in volts)}}{\text{R (in ohms)}}.$$

From which $$e = i \cdot \text{R}.$$

This is the difference in electrical pressure existing between the ends of a resistance R when a current (i) flows through it, and is called the *potential drop* (P.D.) or *potential difference* in the resistance.

The relation $i = \frac{e}{\text{R}}$ is known as *Ohm's Law*, and holds for all direct-current circuits.

Electrical Power.—When a current i (in amperes) flows through a circuit containing a resistance R (in ohms) for a period of t seconds, there is a definite heating effect on the resistance. This is expressed by the following equation :—

$$\text{Heating effect in joules} = i^2 \text{R} \cdot t.$$

In other words, the energy dissipated in heat in 1 second is i^2R joules. This is known as *Joule's Law*.

Since $e = i \cdot \text{R}$, the energy dissipated per second can also be expressed as $i \cdot e$.

Energy per second is called *power* (which is expressed in watts), so that

$$\text{W (watts)} = e \text{ (volts)} \times i \text{ (amperes)}.$$

Thus, when an E.M.F. of e volts is applied to a circuit containing a resistance of R ohms and the current resulting in the circuit is i amperes, the power is ($e \times i$) watts, and the heating effect on the resistance per second is i^2R.

Once the electrical energy is converted into heat, this energy

is lost from the circuit, and power lost in this way is frequently called the i^2R loss.

Connection of Resistances in a Circuit.—There are two ways of connecting resistances in a circuit, namely, (*a*) Series, (*b*) Parallel.

These methods are illustrated in Figs. 2A and 2B.

FIG. 2A.

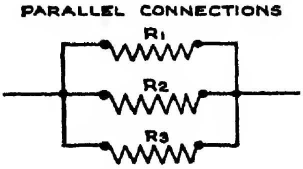

FIG. 2B.

If R_1 = value of first resistance,
R_2 = value of second resistance,
R_3 = value of third resistance,
. . . . . .
. . . . . .
R_n = value of nth resistance,
R = total value of resistance,

then for series connections,

$$R = R_1 + R_2 + R_3 \ . \ . \ . + R_n,$$ i.e. total resistance is increased,

and for parallel connections,

$$1/R = 1/R_1 + 1/R_2 + 1/R_3 \ . \ . \ . + 1/R_n,$$ i.e. total resistance is decreased.

Alternating Current.—So far, only steady or direct currents (commonly indicated by the letters D.C.) flowing along conductors in one fixed direction have been discussed. In other words, a general drift of electrons under a steady potential in one fixed direction has been assumed. Now consider that the E.M.F. is not steady, but reverses its direction rapidly. This implies that the electrons will be under a strain tending to move them in one direction for a certain period of time, and then to move them in exactly the opposite direction. The number of changes of direction per second is termed the ***half frequency***. Frequencies up to 1000 reversals per second are

usually considered as "low frequencies." In wireless work, the number of reversals per second is very much higher, and has a fixed relation to the wave length employed. Thus, a wave-length of 600 metres corresponds to a frequency of 500,000 per second, and the current reverses every $\frac{1}{1,000,000}$ second.

It is obvious that quite different conditions must hold in circuits involving Alternating Current (A.C.) in comparison with those involving Direct Current (D.C.).

Take a simple A.C. circuit as in Fig. 3. Here is shown an A.C. voltage supply producing an A.C. current through a fixed resistance R.

The resistance R varies slightly according to the frequency of the A.C., and increases somewhat with the frequency.

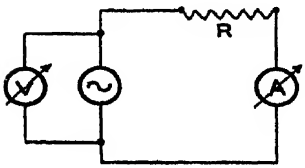

FIG. 3.

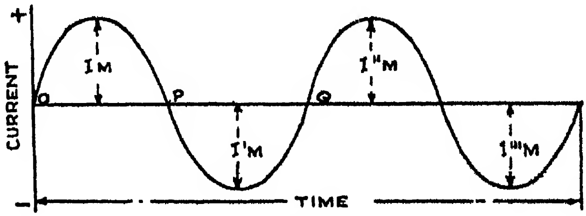

FIG. 4.

The simplest form of A.C. current or A.C. voltage is that which obeys a "sine law," in which case the curve obtained by plotting instantaneous values against time is a sine wave. This is illustrated diagrammatically in Fig. 4.

Here the current starts at zero value, rises to a positive maximum value I_m, and sinks again to zero value at P. At this point the current reverses in direction and rises to a negative maximum value I'_m (where $I_m = I'_m$), and finally reaches zero value again at Q.

The time period OPQ is a complete cycle, and the *frequency* or *periodicity* is the number of these cycles per second. The average value of the current over a complete cycle is zero, as all positive values between OP, and all negative values between PQ, cancel one another.

The effective value of an alternating current is defined in terms of the heating value through a fixed resistance compared with a direct current through a similar resistance.

Let i = value of alternating current at any instant,
$I_{eff.}$ = effective value of A.C.,
R = circuit resistance.

The heating value due to effective value, i.e. *average power* $= I^2R$. Also, the power at the instant when the current is equal to i is i^2R.

Then

$$\text{Mean value of } i^2R = I_{eff.}{}^2R.$$
$$\therefore R \times (\text{mean value of } i^2) = R \,.\, I_{eff.}{}^2,$$
or
$$I_{eff.}{}^2 = \text{mean value of } i^2,$$
i.e.
$$I_{eff.} = \sqrt{\text{mean value of } i^2}.$$

Thus the effective value I equals the square root of the mean value of the squares of all the instantaneous values. This is often called the *root-mean-square value*, or *R.M.S. value* or *virtual value.*

This R.M.S. value is $\frac{1}{\sqrt{2}}$, or 0·707, of the maximum value for a pure sine wave.

Conversely, if I is R.M.S. value, then for a pure sine wave the maximum value is $\sqrt{2}$ I, or 1·414 I (R.M.S. I is the value measured in A.C. ammeters). Similarly with A.C. voltages, if E_m = maximum voltage (peak voltage) and $e_{eff.}$ = R.M.S. value, then

$$E_m = e_{eff.} \times 1{\cdot}414.$$
$$e_{eff.} = E_m \times 0{\cdot}707.$$

If, when the voltage is at maximum value, the current is also at maximum value, and when the voltage is at minimum value the current is also at minimum value, then the current and voltage are exactly " in step " and said to be *in phase.*

With a resistance R in circuit as shown in Fig. 3, the same relation holds as for D.C. circuits, i.e.

$$i_{eff.} = \frac{e_{eff.}}{R} \text{ where } e_{eff.} = 0{\cdot}707E_m.$$

(These circuits obey Ohm's Law.)

Moreover, provided the current and voltage are in phase, the power can be expressed as for D.C. circuits, that is,

$$W_{watts} = i_{eff.} \times e_{eff.}$$

If the current and voltage are not in phase, but differ by an angle ϕ, we have

$$W_{\text{watts}} = i_{\text{eff.}} \times e_{\text{eff.}} \times \cos \phi.$$

"Cos ϕ" is called the *power factor*, and may be expressed by

$$\cos \phi = \frac{W_{\text{watts}}}{i_{\text{eff.}} \times e_{\text{eff.}}}.$$

(*Note.*—See Appendix III. for definition of trigonometrical functions used.)

Condensers.—If two conductors are placed parallel to one another and separated by a suitable dielectric, they form a *condenser*.

The usual form of condenser consists of one or more plates separated from other plates by a dielectric such as air, oil, mica, ebonite, or glass.

If A = area of one set of plates in square centimetres,
d = thickness in centimetres of dielectric between sets of plates,
K = dielectric constant of dielectric used,
C = capacity of condenser in centimetres,

then

$$C = \frac{KA}{4\pi d} \text{ cms. or } \frac{KA}{4\pi d \,.\, 900{,}000} \text{ mfds.}$$

If V = voltage across the plates of the condenser in volts,
Q = quantity of electricity in coulombs.
C = capacity in farads. (A farad is the unit of measurement of capacity),

then $C = \frac{Q}{V}$, i.e. $\frac{i\,.\,t\,.}{V}$ where i = current in amperes
t = time in seconds.

In other words, $1 \text{ farad} = \frac{1 \text{ coulomb}}{1 \text{ volt}}.$

A *farad* is much too large a unit for practical purposes, and is consequently divided into *microfarads*. Using the C.G.S. system the microfarad is again divided into *centimetres*. The relationship is as follows :—

1 farad = 10^6 microfarads (mfds.).
1 mfd. = 900,000 cms.

Energy in a Condenser.—The energy (E) stored in a condenser in the form of electrostatic energy is $\frac{1}{2}$ CV², where C is in farads, V in volts, and E in joules;

or $$E = \frac{\frac{1}{2}C \text{ mfds.} \times V^2 \text{ volts}}{10^6}.$$

Resistance or Reactance of a Condenser.—A condenser is a non-conductor for D.C., but for A.C. it acts as a conductor with a definite resistance, called its *reactance.* The reactance (X_c) of the condenser is dependent upon the frequency of the A.C. and the size of the condenser, and can be written

$$X_c = \frac{1}{\omega . C} \quad \text{or} \quad X_c = \frac{1}{2\pi n C}$$

where $\omega = 2\pi n$, where n = frequency,
C = capacity in farads.

The greater the frequency, the smaller is the reactance. The greater the condenser, the smaller the reactance.

Connection of Condensers in a Circuit.—Condensers may be connected in a circuit in two ways—

(*a*) Series. (*b*) Parallel.

If it is desired to increase the total capacity of a circuit, then the condensers are joined in parallel, as shown in Fig. 5A.

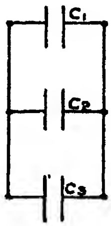

FIG. 5A.

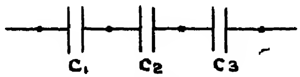

FIG. 5B.

If it is desired to reduce the total capacity of a circuit, then the condensers should be joined in series as shown in Fig. 5B.

Let C_1 = capacity of first condenser,
C_2 = capacity of second condenser,
C_3 = capacity of third condenser,
C_4 = capacity of fourth condenser,
. . . . . .
. . . . . .
C_n = capacity of nth condenser,
C = resultant capacity,

then for *parallel* connection,

$$C = C_1 + C_2 + C_3 + C_4 \ldots + C_n;$$

for *series* connection,

$$1/C = 1/C_1 + 1/C_2 + 1/C_3 + 1/C_4 \ldots + 1/C_n.$$

It is to be noted that an aerial circuit may be regarded as a condenser, and any capacity added in series with the aerial must decrease the total aerial capacity.

The above formulæ should be compared with those for resistances and inductances connected in series and parallel respectively (see p. 5).

Inductance.—Whenever a current flows through a wire, there is a number of *lines of magnetic force* linked with this wire. When the lines of force are changing in number, there is an induced E.M.F. in the wire which is proportional to the rate at which the lines of force are changing. This property of the circuit is called the *self-inductance* of the circuit, and may be defined as that property of an electric circuit in virtue of which an E.M.F. is induced in it whenever the value of the current in it is changing. The *practical unit of inductance* is called the *henry*, and a circuit is said to have an inductance of 1 henry when a current of 1 ampere through the circuit produces 10^8 linkages, or a change of 1 ampere in 1 second produces an induced E.M.F. of 1 volt in the circuit.

Usually, the self-inductance is measured in either millihenries or microhenries or centimetres :—

1 henry = 1000 millihenries.
1 henry = 10^6 microhenries.
1 microhenry = 1000 centimetres.

Reactance of an Inductance.—A circuit containing an inductance has a definite resistance to D.C. current, but a much greater resistance to A.C. This resistance is called the inductive reactance of the circuit, and is expressed by

$X_L = \omega L$ where X_L = reactance in ohms,
$\omega = 2n\pi$, where n = frequency,
L = inductance in henries,

or $X_L = 2n\pi L$.

These expressions show that on increasing the frequency, the resistance increases proportionately. Thus, if the inductive reactance is 50 ohms for a frequency of 100, it becomes 500 ohms for 1000.

Although the D.C. ohmic resistance may be very small, the inductive reactance to A.C. may be large, especially with very high frequencies comparable with those used in wireless. This inductive reactance is just as important in high-frequency A.C. work as ohmic resistance is in D.C. work.

Energy due to Inductance.—Imagine an inductance coil of value L henries having a current i amperes flowing through it. Then the energy (electromagnetic) linked with this coil is

$$E = \tfrac{1}{2}Li^2.$$

Connection of Inductances in a Circuit.—Inductances can be connected in a circuit in two ways—

(*a*) Series and (*b*) Parallel.

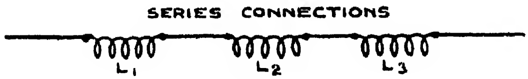

FIG. 6.

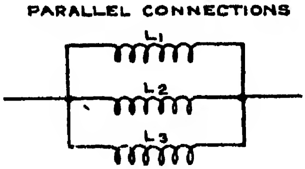

FIG. 7.

To increase the total inductance of the circuit the separate inductances should be in series as in Fig. 6.

To decrease the total inductance of the circuit the separate inductances should be in parallel as in Fig. 7.

If L_1 = inductance value of first coil,
L_2 = inductance value of second coil,
L_3 = inductance value of third coil,
. . . . . .
. . . . . .
L_n = inductance value of nth coil,
L = total inductance value,

then for series connections,

$L = L_1 + L_2 + L_3 \ldots + L_n$, i.e. total inductance is increased;

for parallel connections,

$1/L = 1/L_1 + 1/L_2 + 1/L_3 \ldots + 1/L_n$, i.e. total inductance is reduced.

The above formulæ are similar to those relating to resistances in series and parallel respectively.

Circuit containing Capacity, Inductance, and Resistance.—On page 7 it was shown that the relationship of current to voltage and resistance for a circuit containing resistance with an applied alternating E.M.F. obeyed Ohm's Law.

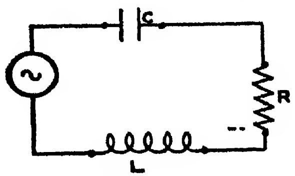

FIG. 8.

Consider the same circuit containing in addition both inductance and capacity, as shown in Fig. 8.

Here we have the total resistance or impedance in the circuit made up of three factors, viz. resistance due to R, resistance due to inductance, i.e. $2n\pi L$, and resistance due to capacity, i.e. $\frac{1}{2n\pi C}$.

The resistance of the inductance opposes a change in current, while that of the capacity aids the current, so that these act in opposition. Then the following relationship holds :

$$i_{\text{eff.}} = \frac{e_{\text{eff.}}}{\sqrt{R^2 + \left(2n\pi L - \frac{1}{2n\pi C}\right)^2}}.$$

Resonance.—Resonance occurs when $2n\pi L = \frac{1}{2n\pi C}$, and in this condition

$$i_{\text{eff.}} = \frac{e_{\text{eff.}}}{\sqrt{R^2}} = \frac{e_{\text{eff.}}}{R}, \text{ i.e. the circuit obeys Ohm's Law.}$$

It is to be noted that a circuit is said to be in resonance with an impressed E.M.F. when the L and C values of the circuit are so arranged that the frequency of the circuit is equal to that of the impressed E.M.F.

It is apparent from this relationship that it is most important to make the ohmic resistance as low as possible, since in the resonance condition the current can be made as high as required by making the ohmic resistance of a suitably low value.

Transformers.—Imagine two windings P (the primary) and S (the secondary) on a former as shown in Fig. 9.

Any A.C. voltage applied to P produces an A.C. voltage of the same frequency in S.

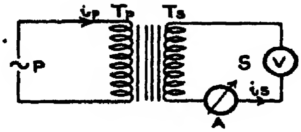

Fig. 9.

The ratio of currents in the primary and secondary windings is practically proportional to the ratio of the number of turns in the primary and secondary.

If T_p = turns in primary,
T_s = „ „ secondary,
i_p = current in primary,
i_s = „ „ secondary,
V_p = voltage in primary,
V_s = „ „ secondary,

then
$$\frac{V_p}{V_s} = \frac{T_p}{T_s},$$

and
$$\frac{i_p}{i_s} = \frac{T_s}{T_p},$$

i.e.
$$\frac{V_p i_p}{V_s i_s} = \frac{T_p}{T_s} \times \frac{T_s}{T_p} = 1,$$

i.e. Primary Watts ($V_p i_p$) = Secondary Watts ($V_s i_s$).

This is approximately true, as transformers are highly efficient pieces of apparatus.

Telephones.—As a sensitive means for detecting weak wireless signals telephones are used. These consist of permanent magnets through which pass the weak rectified currents in the wireless circuit. Over the pole-pieces of the permanent magnets in the telephones are soft iron diaphragms which respond to the smallest changes in magnetic flux due to the current flowing through the windings of the pole-pieces.

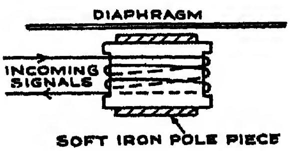

Fig. 10.

Two fluxes must be considered in this case. Firstly, the flux due to the permanent magnet (M_1) and, secondly, that due to the pulsating current through the telephone coils, say, $M_2 \sin . pt$,

The effect of these combined fluxes on the diaphragm is proportional to

$$(M_1 + M_2 \sin pt)^2 = M_1^2 + M_2^2 \sin^2 pt + 2M_1 M_2 \sin pt.$$

The middle term can be neglected owing to its small value. M_1 is a constant. The force causing the diaphragms to vibrate is proportional to $2M_1M_2 \sin pt$. M_1 cannot be increased indefinitely, as this would cause the diaphragm to be saturated. If there flows too strong a steady current through the telephone coils, then the flux M_1 may be so strong that the diaphragm becomes saturated. This would be the case if too strong a direct current flowed from a H.T. battery through the telephone coils, i.e. with the phones directly in the H.T. positive lead. In this case there would be little response from the pulsating flux $M_2 \sin pt$, and the phones would be insensitive. It is best to avoid any direct-current component from the H.T. battery passing through the telephone coils by using a telephone transformer and connecting one side (the secondary) in the H.T. lead and the primary across the telephones. The telephone is essentially a current operated instrument, and consequently the transformer should be of the step-down type, i.e. one in which the large voltage and small current in the secondary is transformed into a small voltage and comparatively large current in the primary. In this case low-resistance phones are used across the primary of the telephone transformer so as to get as big a change of flux as possible for a small change in the value of the pulsating component $M_2 \sin pt$.

The best ratio is approximately S : P = 7 : 1.

CHAPTER II.

VALVES.

As modern wireless practice, both as regards transmission and reception, is mostly based on valves, it is essential that the elementary principles of their operation be understood. As mentioned in an earlier section, when certain elements are heated, e.g. tungsten, or molybdenum (particularly when treated with thorium compounds), they emit a number of small negative particles called electrons, each of which carries a negative charge of electricity. In a valve there are three essential parts, which are usually enclosed in a glass bulb. These parts are :—

(*a*) *The filament*, which usually consists of tungsten or molybdenum treated with compounds of thorium.

(*b*) *The grid*, which usually consists of an open nickel wire cylinder surrounding the filament.

(*c*) *The plate* or *anode*, which usually consists of a circular nickel cylinder surrounding the grid.

These are diagrammatically shown in Fig. 11.

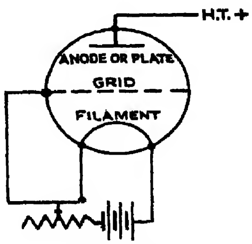

FIG. 11.

The filament is caused to emit electrons by being heated by means of a filament battery or through a filament transformer delivering current at the requisite voltage. The number of electrons emitted by the filament per second depends on the size and type of filament, and on the temperature, and increases with the rise in temperature.

These electrons, having a negative charge, are attracted to the plate, which is positively charged by being connected to the positive terminal of the H.T. battery. By changing the charge on the grid we have a method of controlling the number of electrons reaching the plate, and consequently the current

in the plate circuit. If negatively charged, the grid will oppose the passage of the negative electrons through it, and thus diminish the current in the plate circuit. If, on the other hand, the grid is positively charged, it will help the passage of the electrons to the plate, causing an increase in the plate current.

Moreover, there will be a big increase in volts on the plate for a small increase of volts on the grid. If, for example, the grid potential is changed by 1 volt, and the effect on the plate current is such that to achieve the original plate current the plate voltage must be decreased by 5 volts, then the *amplification factor* or *amplification constant* (frequently called the μ value) of the valve is said to be 5. The amplification factor varies considerably for different types of valve.

Anode Current—Grid Voltage Characteristic.—As the grid voltage governs the anode current, a characteristic curve can be drawn showing the variation of the anode current with varying grid volts.

The valve filament is heated by a battery, and varying voltages are applied to the grid by means of a grid battery

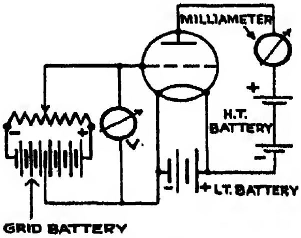

FIG. 12.

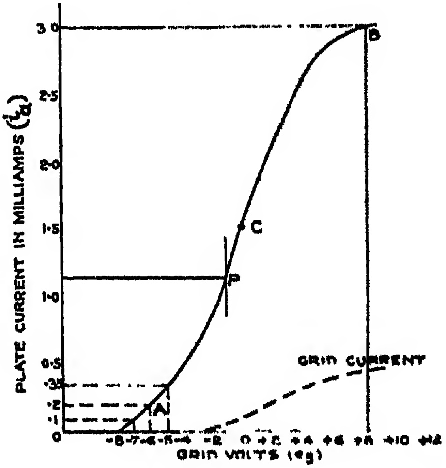

FIG. 13.

connected across a sliding resistance. In the plate circuit is a high-tension battery, the positive of which is connected to the valve plate and the negative to the L.T. positive terminal. Included in this circuit is a milliammeter for measuring the value of the plate current.

Fig. 13 represents a typical anode current—grid voltage characteristic curve. With 8 volts negative on the grid there is no plate current. The plate current increases with increasing grid volts until at + 8 volts it reaches a maximum value of

3 milliamperes. Any increase of grid volts over + 8 does not increase the anode current. In other words, all electrons generated at the filament have been carried across to the plate. The valve is said to be *saturated.*

When the grid volts are such that the voltage of the grid is higher than that of any portion of the filament, a " grid current " passes, that is to say, a current flows along the path filament-grid.

Valve as a Detector.—If an incoming wave is applied to the grid of the valve connected as in Fig. 14, functioning on the point A of the curve shown in Fig. 13 (6 volts negative grid bias), the grid will have an alternating E.M.F. impressed upon it. The positive half of the first oscillation will raise the grid volts from — 6 to, say, — 5, and the plate milliamperes will accordingly change from 0·2 to 0·35. The second half of the first oscillation will lower the grid volts from — 6 to — 7, and lower the plate milliamperes from 0·2 to 0·1.

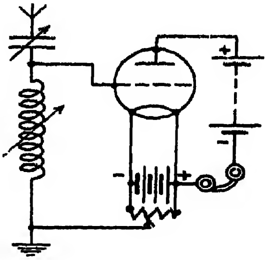

Fig. 14.

Thus the plate milliamperes follow the change in the grid volts, but not symmetrically. In other words, the *mean plate current* will be raised above that corresponding to the point A.

The effects of two trains of incoming signals are shown in Fig. 15.

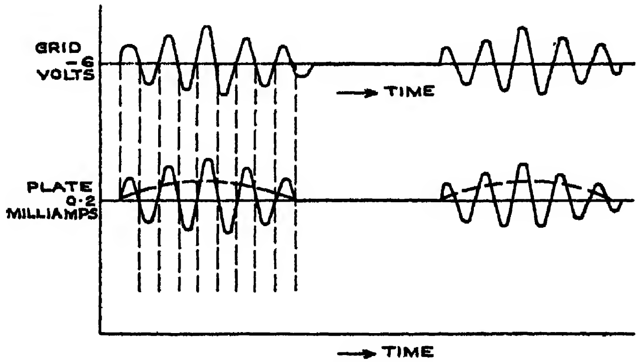

Fig. 15.

The wave-trains cause the grid volts to fluctuate about their mean value of — 6 volts, while the plate milliamperes

vary about their steady value of 0·2 milliampere, so that there is a slight increase in the steady main current in the plate circuit. This is shown by the dotted line. Now, this increase in the mean steady plate current will be recorded by the telephones, which are only sensitive to a *change* in current. Thus to each *train of waves* we get a corresponding sound in the telephones.

Here the valve is acting as a " detector " of the incoming oscillations.

A similar result could be obtained by working the valve at point B near the saturation bend ; only at this point one would find a decrease in the mean plate current, and not an increase as at the point A. It is to be noted that the grid is sufficiently negative when working on point A, to prevent any flow of grid current. In this case no energy is drawn from the oscillating receiver circuit, so that this circuit is not damped by the action of the valve.

Leaky Grid—Condenser Rectification.—A very common method of connecting a detector valve in circuit is as shown in Fig. 16.

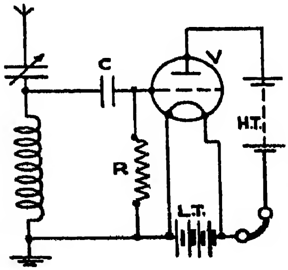

Fig. 16.

Here the grid of the valve V is connected through a small condenser C to the source of oscillating potential (in the above case the received energy in the aerial). A high resistance R is connected between the grid and the positive end of the filament of the valve V.

The action may be explained as follows :—

In the above scheme of connections the grid is at a higher potential than the negative end of the filament, and therefore electrons will flow from the filament to the grid. If a grid current i_g is flowing in this circuit through the high resistance R, then the voltage drop in this resistance is i_gR, and, assuming the grid to be connected to the positive end of a 6-volt battery, the grid potential, with respect to the negative end of the filament, is $6 - i_g$R volts.

The valve is now functioning at a point, say, P on the curve shown in Fig. 13, i.e. with a certain definite grid current as well as plate current.

If an oscillation of incoming energy is picked up on the

aerial, then the varying potential due to the signal will be transferred to the grid of the valve through the condenser C. A negative pulse will cause the valve to function at a point on the curve to the left of the point P, while a positive pulse will cause the valve to function at a point on the curve to the right of P and increase the grid current by drawing more electrons to the grid. This increase in the grid current i_g will cause an increase in the value of the potential i_gR. This means that the grid potential value of $(6 - i_g\text{R})$ is reduced, causing a corresponding decrease in the value of the plate current, and producing signals in the telephones T. As soon as the extra charge on the grid, due to the positive pulse from the incoming signal, has leaked away through the high resistance R, the grid returns to its normal potential $(6 - i_g\text{R})$, i.e. the valve returns to the point P on the curve in Fig. 13.

For spark signals the resistance should be of such a value that the above action takes place during the interval between sparks. The value of the condenser C must be such that it is larger than the capacity of the valve itself, as otherwise oscillating potentials due to the incoming signals will not be transferred to the valve grid with full effect. If C is too large, then the effect produced on the grid by the oscillating potential due to the incoming signal will be small, because this oscillating potential would have but a small effect in the way of changing the potential of a large capacity.

The actual size of this condenser is dependent on the frequency and the amplitude of the incoming signal. For normal working 300-400 cms. capacity is suitable.

The value of the grid leak resistance R is dependent on the condenser C. The important point is that the reactance of the condenser C, i.e. $\frac{1}{2n\pi\text{C}}$ for the frequency (n) of the incoming signal, should be small in comparison with the resistance R, in which case the high-frequency oscillating currents will flow to the valve through the condenser C, and not leak away through the resistance R.

The usual value of R is 2 to 3 megohms, but this value is, in general practice, not a critical quantity.

Valve as a High-frequency Amplifier.—Suppose the valve whose characteristic is shown in Fig. 13 works under

conditions represented by the point C. Then any increase or decrease in the grid volts would show a large change in the value of the plate current, but as the amount of positive change would equal the amount of negative change, the mean value of the plate current would not alter. The oscillations in the plate circuit would, however, be greater in amplitude than those on the grid, and would be in synchronism with those impressed on it.

Under these conditions the valve acts as a high frequency amplifier, and the amplification factor of the valve is a measure of the increase in amplitude of oscillation.

Valve as a Low-frequency Amplifier.—This is the most common use of a valve. A typical circuit is shown in Fig. 17.

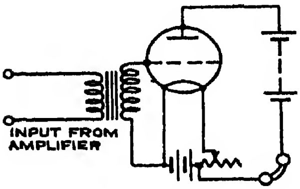

FIG. 17.

In this case the grid of the valve is connected to the secondary of an intervalve transformer. The primary of the intervalve transformer is connected to a means of current rectification (detector valve or crystal). Compare this with high-frequency amplification.

It has already been shown that the valve acts in such a way that at any point other than the detector acting parts of the characteristic curve, i.e. at points other than at the bends of the curve, it follows all fluctuating changes of potential at any frequency and in synchronism with that frequency. Moreover, there is an amplification on the initial voltage applied to the transformer primary through the ratio of the windings of the transformer. This stepped-up voltage is applied to the grid of the valve, and produces a resultant step-up in the anode current and in the telephone current. In other words, the valve acts as a relay.

COUPLING BETWEEN VALVES.

High-frequency Tuned Anode Coupling.—One of the commonest methods is shown in Fig. 18.

The high-frequency potentials received on the grid of V_1 are amplified by V_1 and the amplified E.M.F.'s alternate in the anode circuit of V_1. If the latter circuit—consisting of an inductance L_1 and a capacity C_1—is brought into resonance, conditions of maximum current and maximum E.M.F. result

(see p. 12). This circuit is connected to the grid of V_2 through a condenser C_2, and thus any changes in E.M.F. in L_1 C_1 are transmitted through the condenser C_2 to the grid of valve V_2.

The size of C_2 must be such that its reactance value $\frac{1}{2n\pi C}$ is small compared with the resistance of the shunt r_2 for the frequency of the wave received.

This is the most efficient form of H.F. coupling.

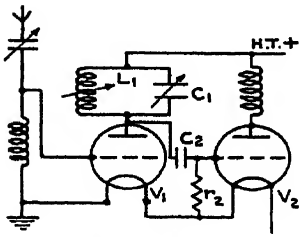

FIG. 18

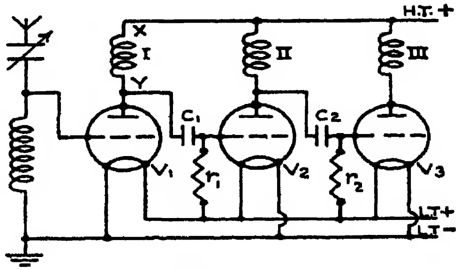

FIG. 19.

High-frequency Choke Coupling.—Another common method of coupling H.F. valves is by means of chokes. These consist of a large number of turns of high-resistance wire wound on a former.

The method of connection is shown in Fig. 19.

Incoming oscillations on to the grid of V_1 cause an alternating current i_p in the plate circuit of V_1, i.e. in choke I.

If the resistance of the choke at the frequency being received is R, there is a voltage drop i_pR across the points XY.

As C_1 is connected to Y, then any fluctuation in voltage in XY is transmitted through C_1 to the grid of the valve V_2.

It is to be noted that the chokes have a resonance frequency to a single wave-length, i.e. to that incoming wave-length which is in resonance with the natural wave-length of the choke.

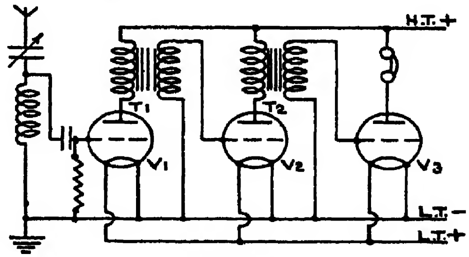

FIG. 20.

Low-frequency Coupling (Transformers).— Low-frequency coupling is most frequently carried out by means of intervalve transformers. A typical case is shown in Fig. 20.

Here is shown a detector valve V_1 followed by two low-frequency amplifying valves V_2 and V_3, which are coupled by means of the low-frequency transformers T_1 and T_2.

In modern practice one endeavours to make the impedance of the transformer primary equal to the internal resistance of the valve used in order to obtain the most efficient results per stage.

Resistance Coupling.—A simple case is shown in Fig. 21. Here again is shown a detector valve V_1 and two low-frequency amplifying valves, V_2 and V_3. R_1 and R_2 are resistances of about 1 to 2 megohms for normal H.F. valves, and 2 to 3 megohms for high voltage factor valves, while r_1 and r_2 are about 3 to 5 megohms each.

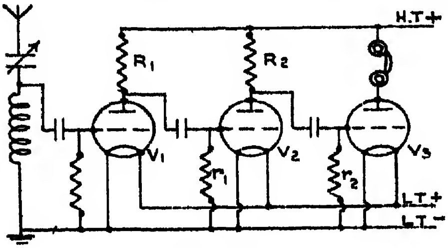

FIG. 21.

The transference of E.M.F. in this case occurs in a similar way to that described on page 21, except that modulated unidirectional current, and not alternating current, is being dealt with.

REACTION.

Inductive Reaction.—Consider a circuit as in Fig. 22.

It has already been demonstrated (Fig. 15) that the variation in the plate circuit current is exactly synchronous with the fluctuations of grid potential, and may, or may not, be accompanied by a low-frequency pulse in the mean value of the plate current, dependent on the part of the characteristic curve on which the valve functions.

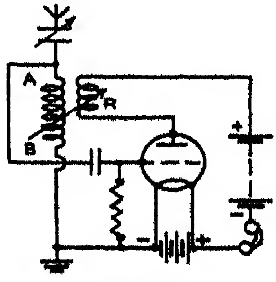

FIG. 22.

If a coil R, in which the plate current is passing, is coupled to the aerial coil AB, any oscillations in R will induce an oscillating potential in AB. Thus the oscillations produced in the aerial by the incoming wave pass through the valve, causing oscillations in the plate current. These oscillations flowing through coil R induce additional

potentials in the aerial which are synchronous with, and amplify the effects due to, the incoming oscillations.

This coil R is called a *reaction coil*, and care must be taken that the direction of the induced oscillations from R into the aerial are helping the incoming oscillations. Should they oppose the incoming oscillations, a total "wipe out" of signals would be the result. The use of reaction is one of the most usual methods of increasing signal strength.

It should be noted that this means of reaction (inductive reaction) employs two dispersed fields, i.e. the field due to the aerial coil AB and the field due to the reaction coil R.

Capacity Reaction.—The same result as the above may be achieved by using capacity reaction instead of inductive reaction.

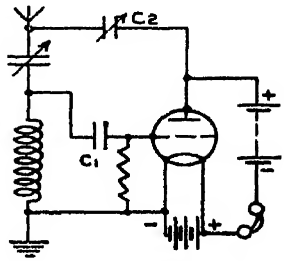

Fig. 23.

This is shown in Fig. 23.

In this case the oscillations in the plate circuit of the valve are coupled back into the aerial by means of the condenser C_2.

This method of capacity reaction gives a very concentrated field.

Heterodyning.—By this method of reception is understood *beat reception*. It is well known that a C.W. oscillation of, say, 1000 metres wave-length, i.e. of a frequency 300,000 per second, cannot be followed by telephones, or by the human ear. If, however, a frequency of 301,000 per second, or 299,000 per second, be superimposed on that of 300,000, a "beat frequency" of 1000 per second is produced, which frequency can be followed by the phones, and the resultant sound wave from the phone diaphragms by the human ear. If the difference between the incoming frequency and the superimposed frequency is too great, then the resultant beats become inaudible, and if the difference becomes too small the resultant beats are again inaudible. The region of inaudibility due to the beat frequency being below the audible range is called the "silent point" or "dead spot."

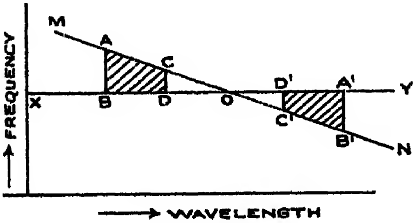

Fig. 24.

The phenomenon of beat reception is illustrated in Fig. 24.

XY represents a steady incoming oscillation, while MN represents the change in frequency of the superimposed oscillation.

The shaded areas A, B, C, D, A^1, B^1, C^1, D^1 represent the areas of audibility of the beats. O is the silent point.

Local Oscillator.—The best method of producing superimposed oscillation is by means of a local valve oscillator.

This local oscillator (L.O.) is shown in Fig. 25. It consists of a valve whose grid and plate circuits are coupled in such a way that the valve oscillates. Arrangements are made, either in the grid or plate circuit of this valve, for tuning. In the case illustrated below, a condenser is placed in the grid circuit. The incoming continuous wave signals are received on the aerial

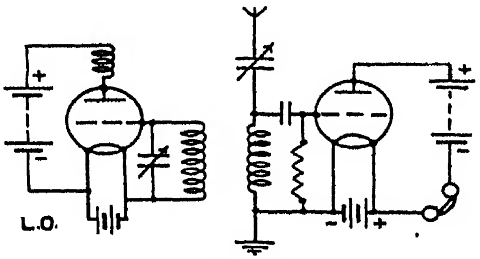

FIG. 25.

system, with which they are in tune. Then the local oscillator is coupled to the aerial system and slightly mistuned from the incoming waves. The resultant beats between the frequency of the incoming waves and the frequency of the local oscillator are rectified by the valve in the receiver, and the signal is received in the telephones, the frequency of the note heard in the phones being equal to the difference in the frequency of the local oscillator and the frequency of the incoming signal.

In this way a very weak incoming signal can be considerably strengthened by the energy obtained from the local oscillator.

So far incoming C.W. signals only have been considered. Spark signals may also be received by heterodyne methods. This considerably increases both the strength of the incoming signal and the selectivity of the receiver, the chief disadvantage being that the characteristic note of the spark transmitter is lost. Moreover, it is to be noted that if spark signals are

received by beat or heterodyne methods of reception, there is no silent point. This is due to the fact that no matter how sharp the tuning of a spark transmitter may be, it does not radiate a single pure wave on one wave-length, but a number of different wave-lengths about a maximum value. A number of frequencies are, therefore, induced into the receiving system.

Screening.—By screening is understood a method of protecting apparatus from external electric and magnetic influences.

In considering the screening of electrical apparatus two distinct effects must be considered, namely,

(*a*) Screening of the electrical field of the wave.
(*b*) Screening of the magnetic field of the wave.

Screens can be so arranged that they cut out either (*a*) or (*b*), or both (*a*) and (*b*).

First consider the type of screen suitable for cutting out

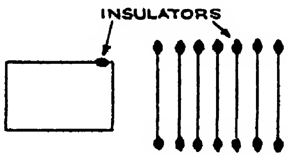

FIG. 26.

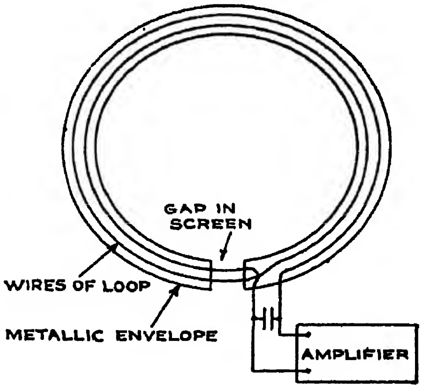

FIG. 27.

the *electrical field* of the wave front without influencing the magnetic field. This must be such that the individual conductors of the screen are open circuits. This can be achieved by

(*a*) Straight insulated wires.
(*b*) Open loops.

These are shown in Fig. 26.

This type of screen, while very effective as regards cutting out the electric field, has practically no effect on the magnetic field.

If a type of screen of this nature could be employed for screening in D.F. work, a means would be available of either cutting out or at least reducing the *vertical effect* (see pp. 41-46) in the receiver. This would considerably sharpen up the minima

obtained. This type of open loop screen for a single frame may be in the form shown in Fig. 27.

Here the wires of the loop are wound inside a metallic envelope and carefully insulated from it. A gap is introduced into the screen as shown.

If this gap is open even a small fraction of an inch, then signals are obtained on outside stations and the minima are very sharp, showing the absence of " direct vertical " effect. If, however, the loop is closed, then no signals are obtained, indicating total screening both of the electric and magnetic fields of the incoming wave.

To screen an instrument from the *magnetic field* without influencing the electric field, the following method may be adopted :—

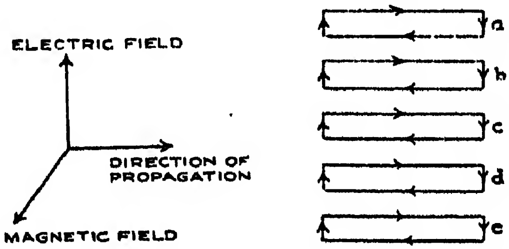

FIG. 28

Imagine a system of closed elongated loops *a*, *b*, *c*, *d*, *e*, as shown in Fig. 28, arranged in such a way that there is no continuity in the direction of the electric field. Then the currents induced in these loops will be in the directions indicated by the arrows. It is to be noted that the currents in the adjacent horizontal portions will have opposing effects at points not close to them. The effective currents will be those in the boundary conductors.

To screen from the magnetic field it is essential to have closed conducting paths surrounding the apparatus to be screened. Any path, however, only screens from that component of the magnetic field which is perpendicular to its plane. Thus, totally to screen apparatus there should be three conducting paths at right angles to one another. This is accomplished by having a box with all sides and the top and the bottom of metal, and the top and bottom must make good

electrical contact with the sides. If the box is open at the top or at one side, it will only screen efficiently from those magnetic fields which are perpendicular to the open face.

If controls are introduced into the box by means of small holes through the metal screen, parts situated inside the screen will not be appreciably affected by the holes.

It must be remembered that it is extremely difficult to produce a perfect screen. The smallest gaps allow energy to penetrate the screen. On the other hand, ordinary wire netting of 2-in. mesh will prevent 90 per cent. of energy from going through the screen.

CHAPTER III.

PRINCIPLES OF DIRECTION FINDING.

An Oscillating Circuit.—Before the principles of direction finding can be understood, the student must have a clear idea of what is meant by a wireless wave, how this is generated, how it leaves the transmitting aerial, how it passes over the intervening medium to the receiver, and how it is actually received.

To take a simple example of how the wave is generated, consider a simple oscillating circuit consisting of an inductance (L) and a capacity (C) supplied by a H.T. supply, and having a spark gap (S.G.) in series with the inductance and capacity.

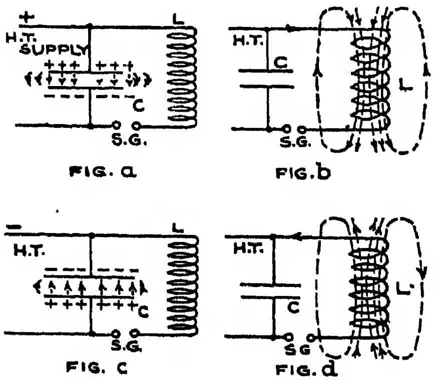

FIG. 29.

The cycle of the oscillations is illustrated in Fig. 29. The H.T. supply charges up the condenser C until the spark gap S.G. breaks down. Before this occurs, all the energy is stored in the condenser in the form of electrostatic energy equivalent to $\frac{1}{2}CV^2$, where C = capacity of condenser in farads and V = pressure in volts to which the condenser is charged (see p. 9). Soon after the condenser breaks down, the condition is as shown in (*b*), where the energy becomes linked with the inductance in the form of lines of electromagnetic force. The energy has now been converted into electromagnetic energy and is equal to $\frac{1}{2}Li^2$, where L = inductance in henries and i = current in amperes through the inductance (see p. 11).

In the third position of the cycle, the condenser C becomes charged in the opposite direction, as indicated in Fig. 29c.

Here again the energy is electrostatic, but the charge is opposite to that in Fig. 29A.

Finally, the cycle is completed as in Fig. 29D. Here it is again electromagnetic energy, but with the reversed sign compared with Fig. 29B.

The frequency of repetition of these cycles is dependent on the values of the inductance and capacity in the circuit. The time of a complete oscillation is given by

$$T = 2\pi\sqrt{LC} \text{ where } L = \text{inductance in henries.}$$
$$C = \text{capacity in microfarads.}$$
$$T = \text{time in seconds.}$$

The *frequency of oscillation* is $n = \frac{1}{T} = \frac{1}{2\pi\sqrt{LC}}$.

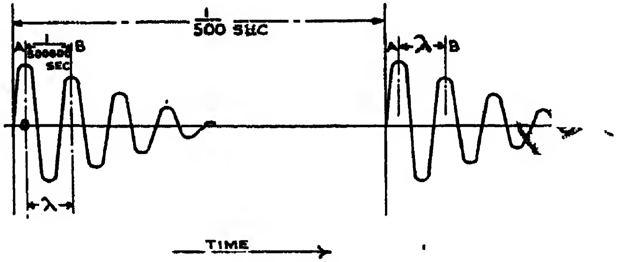

FIG. 30.

When once the cycle has been started, it persists until the energy is expended in oscillations, which produce a wave train as in Fig. 30.

OA is the *amplitude* of the oscillation, and is dependent on the initial energy. AB is a *wave-length*. If the wave-length (AB) is 600 m., the time for one complete oscillation is $\frac{1}{500,000}$ second. The frequency with which the condenser in Fig. 29 is charged gives the frequency of the trains, which is usually about 1000 per second in commercial transmitters.

In a *continuous wave* transmitter the wave system produced can be represented as in Fig. 31.

Here the waves are emitted in a continuous train with a constant amplitude, and there is no interruption in the train as is the case in spark transmission.

In *I.C.W.* or *interrupted continuous wave* transmission, the wave trains are almost identical with those occurring in spark

transmission, the only difference being that there is no damping as in Fig. 30. This is illustrated in Fig. 32 for a 600 m. wave with a 1000 note frequency.

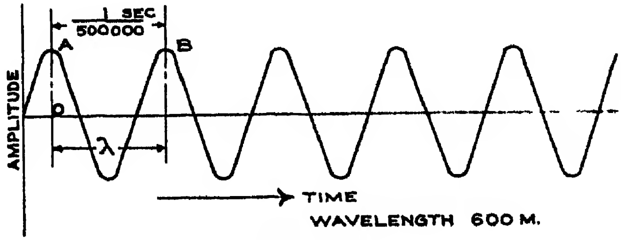

FIG. 31.

Now imagine this oscillating system coupled in some manner to an aerial system. Then exactly the same state of affairs exists in the aerial system, namely, that the energy is oscillating

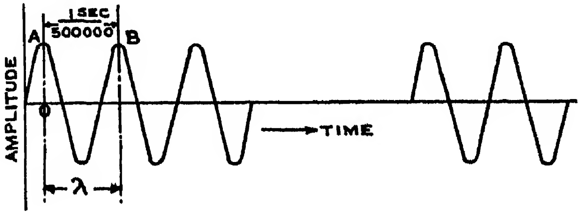

FIG. 32.

between *electrostatic* and *electromagnetic* energy. Imagine the aerial to contain all *electrostatic energy*, i.e. to be charged. This is represented by Fig. 33.

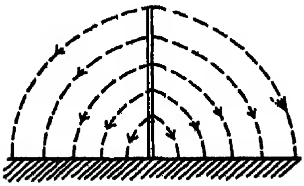

FIG. 33.

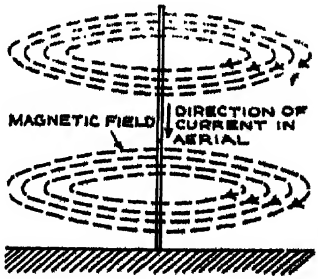

FIG. 34.

When the aerial is charged, a system of lines of *electrostatic* force run at right angles to the earth's surface.

Imagine the aerial energy to be all *electromagnetic* as in Fig. 34.

Here the aerial is linked with lines of *electromagnetic force* parallel to the earth's surface.

The lines of electrostatic and electromagnetic force emanate from all points on the aerial.

Actually, the radiated wave consists of a combination of these fields, which are at right angles to one another and at right angles to the *direction of propagation* of the wave as shown in Fig. 35.

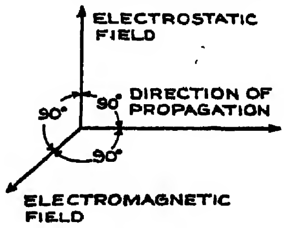

FIG. 35.

When considering the action of the wave on a receiving aerial of any type, it is simpler and substantially correct to consider only the electromagnetic component.

Consider the distribution of the fields at a distance from the transmitting aerial.

The simplest form of straight wire aerial may be represented as in Fig. 36.

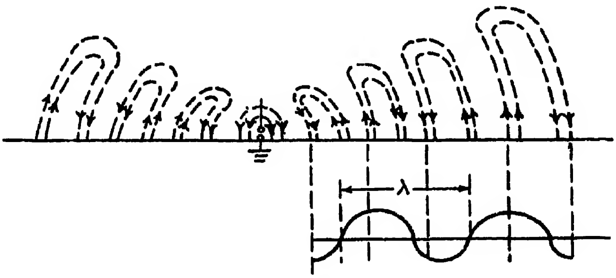

FIG. 36.

The loops of energy are radiated over the earth's surface, gradually straightening up to a certain point. Beyond this point, the top of the wave falls over and leads the foot of the wave. This is shown diagrammatically in Fig. 37.

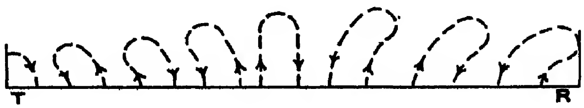

FIG. 37.

T. = TRANSMITTER. R = RECEIVER.

Taking a plan of the aerial, the distribution of the *magnetic lines of force* is as in Fig. 38A.

These lines of force spread out and are as Fig. 38B at a distance from the aerial.

The *density* of the lines of force or *flux density* can be shown to be as in Fig. 39.

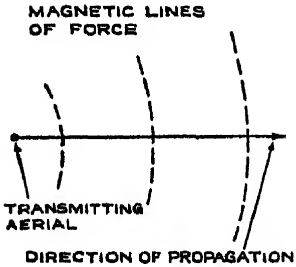

FIG. 38A.

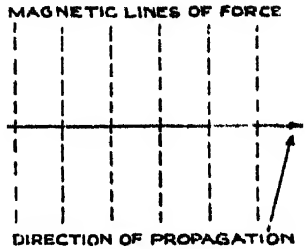

FIG. 38B.

Viewing a wave-length OB, O is a point of minimum flux, which flux rises to a maximum at X, and then falls to a minimum at A. Here occurs reversal in sign, and the flux density rises to a maximum at Y and again falls to a minimum at B.

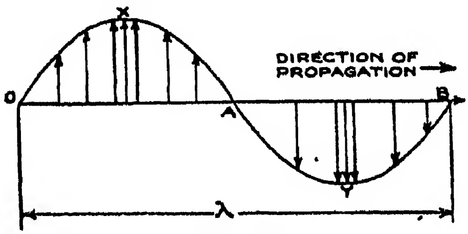

FIG. 39.

A straight wire conductor (a receiving aerial) placed in the plane of the advancing wave front acts as a conductor placed in a moving magnetic field, and an E.M.F. is induced in the conductor. This E.M.F. is proportional to the number of lines of force cutting the conductor per second.

In the position represented by PQ (Fig. 40) the flux density is nil, and no E.M.F. is induced in the conductor. In position P^1Q^1 the conductor is in a position of maximum flux, and a maximum E.M.F. will be induced in the conductor. Assume this direction of E.M.F. is positive. At $P^{11}Q^{11}$ the flux density is again zero, and the E.M.F. induced consequently zero. At $P^{111}Q^{111}$ the flux density is again maximum and the E.M.F.

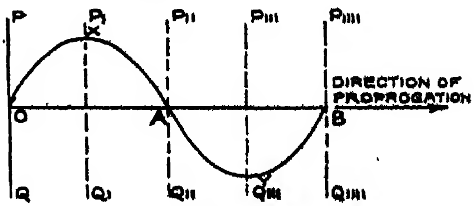

FIG. 40.

induced is maximum, but in the opposite direction to that induced at P^1Q^1. Finally, at $P^{1111}Q^{1111}$ the flux density and induced E.M.F. are again zero.

Consequently there is induced in a vertical receiving aerial an E.M.F. which is *in phase* with the flux of the incoming wave. This may be represented by the sine curve OXAYB in Fig. 40. Moreover, it has been previously stated (p. 32) that the greater the flux density, i.e. the greater the number of lines of force cutting the aerial, the greater is the amplitude of the E.M.F. induced in the aerial and the greater the current. This explains why a high vertical aerial cut by the maximum number of lines of force gives louder signals than a low flat aerial where the number of lines of force cutting it is less.

In order to raise this E.M.F. to a maximum, the constants of the aerial must be suitably adjusted. Every aerial has a certain value of *inductance, capacity,* and *resistance.* The latter comprises (*a*) *ohmic resistance,* (*b*) *earth resistance,* and (*c*) *radiation resistance.*

With reference to item (*c*), it must be understood that as soon as an E.M.F. is induced in the aerial, the latter begins to radiate, so that it is necessary to take the radiation resistance into account. This again is a maximum for a long straight vertical aerial.

Now, the E.M.F. in such a system may be represented by

$$e = i\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$$

where i = effective current in amps.
e = effective E.M.F. in volts.
R = resistance in ohms.
L = inductance in henries.
C = capacity in farads.

and $\omega = 2n\pi$
$\pi = 3 \cdot 1416$
n = frequency.

In the position of resonance, the inductive reactance (ωL) equals the capacity reactance $\frac{1}{\omega C}$.

Thus the E.M.F. becomes a maximum when we attain resonance between the incoming wave frequency and the receiving aerial system, and the equation becomes $e = iR$, which is simply Ohm's law (see p. 12).

Moreover, the smaller R is made the greater will be the value of the induced E.M.F., and consequently the louder the signals received. R can be made small by carefully choosing the type of wire used in the circuits connected with the aerial system and by keeping all losses at a minimum. Care should also be taken to ensure a good earth and so keep the earth resistance at a minimum.

Loops.—Now consider a reception system such that instead of having a single vertical earthed wire, two vertical wires AB and CD, joined across the top by a straight wire AC and connected to a capacity (K) in the lower lead, are employed. This gives an oscillatory system as shown by Fig. 41, commonly termed a *loop system*.

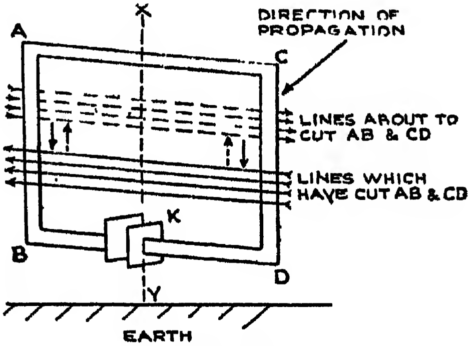

FIG. 41.

This system may be investigated in the same manner as the vertical aerial system, and quite independently of the amplification system used in conjunction with the loop.

By merely considering the effect of the electromagnetic component of the wave, as hitherto, the effect on the two conductors AB and CD need only be dealt with ; limbs AC and BD may be ignored. These always lie along the plane in which the lines of magnetic force arrive, and in consequence no E.M.F. is induced in them.

On the other hand, the conductors AB and CD are always at right angles to the lines of magnetic force, and therefore have an E.M.F. induced into them as though they were two vertical aerials.

These limbs are not, as in the previous case of the single

vertical aerial, connected to earth, and the current developed in the loop will be dependent upon—

(*a*) The E.M.F.'s induced in AB and CD, respectively, and
(*b*) The directions of these two E.M.F.'s relative to one another.

Conditions for Minimum Signal Strength.—Imagine this loop to rotate about a centre axis XY, and that the direction of propagation of the wave is as shown in Fig. 41, i.e. advancing out of the plane of the paper towards the reader, and that the frame is placed at right angles to the direction of propagation. Then the vertical conductors AB and CD are cut by the lines of force at exactly the same moment. In each conductor an E.M.F. is induced which is in the same direction relative to the loop, i.e. if at any moment in AB it is downwards towards the earth, it is also downwards towards the earth in CD. Also, the magnitudes of these two E.M.F.'s are equal. Therefore, the E.M.F.'s in the two limbs of the frame neutralise one another and the effective E.M.F. in the loop is zero, and if a detecting device be placed across the loop no signals will be received.

Thus it is seen that the signal strength is zero when a loop aerial is placed at right angles to the line joining the transmitter station and the loop.

Conditions for Maximum Signal Strength.—Now rotate the plane of the loop about XY in such a way that it is at an

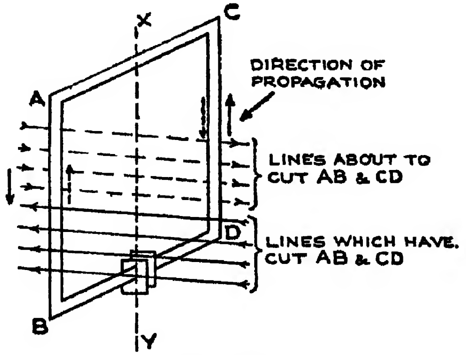

FIG. 42.

angle of 90° relative to its previous position, i.e. with the plane of the loop in the same line as the direction of propagation of the wave. This is shown in Fig. 42.

In this case the frame is pointing in the direction of the transmitting station.

In Fig. 42 a wave front coming out of the paper towards the reader will cut CD slightly in advance of AB. Thus the E.M.F. generated in CD will be always slightly ahead of that in AB, and the E.M.F.'s generated will be slightly out of phase with one another. The two E.M.F.'s will, therefore, not be equal and opposite to one another as in Fig. 41.

Thus the resultant E.M.F. in the loop will be the sum or difference of the E.M.F.'s generated in AB and CD, according to whether they are acting in the same direction or in opposite directions round the loop at a given instant.

Phase Relationship of the Flux of the Incoming Wave and the Induced E.M.F. in Loop.—Now consider this resultant E.M.F., both as regards magnitude and phase, in relation to the separate E.M.F.'s generated in the conductors AB and CD.

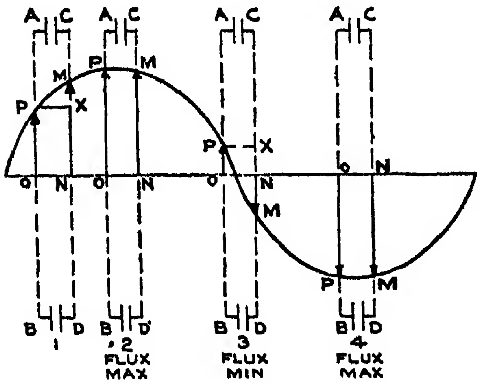

Fig. 43.

Fig. 39 has shown how the flux density of the wave varies.

Imagine the conductors AB and CD to move over the wave as shown in Fig. 43.

The E.M.F. generated in the frame is proportional to the flux density of the wave, and the E.M.F. generated in the conductors by the first half of the wave is of opposite sign to that generated by the second half.

Thus the generated E.M.F.'s in the frame at the various points along the wave are shown by the verticals OP and NM, and the directions of the E.M.F. by the arrows at P and M.

In position 1 the resultant E.M.F. in the frame is the difference (NM — OP), i.e. XM and flowing round the frame in the direction XM.

In position 2 the resultant is zero ; also in position 4.

In position 3 the resultant E.M.F. is equal to XM and is a maximum.

It is to be noted that—

(1) When the flux density is a maximum (in positions 2 and 4), the E.M.F. in the frame is zero.

(2) When the flux density is zero (in position 3, i.e. 90° after position 2), the E.M.F. in the frame is a maximum.

Thus the effective E.M.F. generated in the frame will alternate at the frequency of the incoming wave, *but will be* 90° *out of phase with the flux of the incoming wave.* The position for maximum E.M.F. and maximum signal strength in a receiver connected to the frame occurs when the frame is pointing at the transmitting station. This should be carefully compared with the fact that the E.M.F. induced in a vertical aerial *is exactly in phase with the flux of the incoming wave.*

That is, the E.M.F.'s generated in a vertical aerial and a loop aerial placed side by side and cut by the same wave are exactly 90° *out of phase with one another.*

Polar Diagrams (General Principles).—These form an exceptionally convenient method of visualising effects both of transmission and reception.

To take a simple case, imagine a transmitter sending with constant signal strength at a point O, and a means of measuring the received signal strength, e.g. a receiver and a Moullin voltmeter. Then, if the signal strength is measured at every 30° around the aerial, and the value of this measured strength set out along straight lines radiating from a point, the resultant curve may take the shape such as shown in Fig. 44.

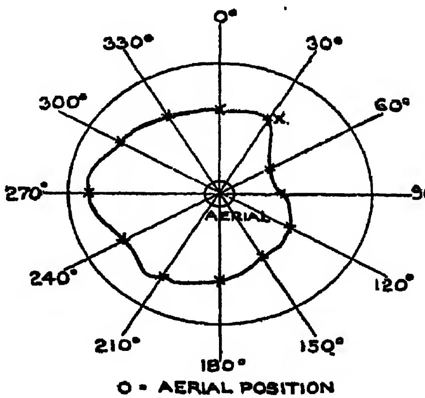

FIG. 44.

This curve then shows the intensity of the received or transmitted signals at any point.

Thus OX indicates both (*a*) direction of signal and (*b*) intensity of signal.

Summation of Polar Diagrams.—To find the resultant effect of two polars, proceed as follows :—

Imagine a circular polar OP, P_1, P_2, etc. (Fig. 45), which is assumed to be negative in sign and a polar OQ_1, Q_2, etc., of opposite (positive) sign superimposed upon it.

To find the resultant effect take a number of radii from O to the polar OP, P_1, P_2, etc. Let these cut the polar O, P_1, P_2, P_3, etc., and the polar OQ_1, Q_2, etc., at points Q_1, Q_2, Q_3, etc.

Now in the direction OP_1 the resultant is $- OP_1$ (since the sign of OP_1, P_2, etc., is negative).

In the direction OP the resultant is $- OP + OQ$ which, being of equal value, gives a value zero, i.e. point O.

In the direction OP_2 similarly ($- OP_2 + OQ_2 =$ say OR_2).
" " OP_3 " ($- OP_3 + OQ_3 =$ say OR_3).

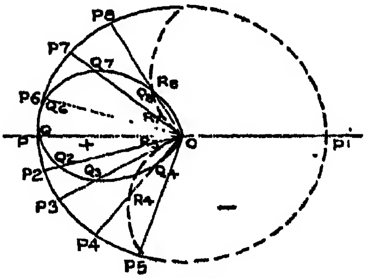

Fig. 45.

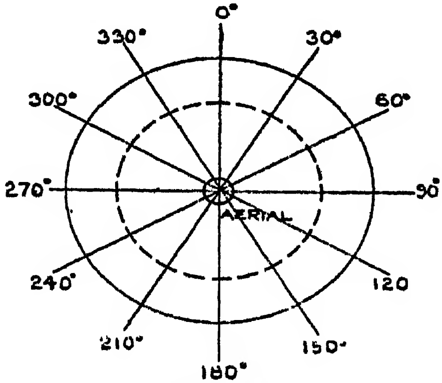

Fig. 46.

The result of taking a large number of radii is the completed polar P_1, R_2, R_3, R_4, etc., which is the resultant effect of superimposing the two polars on one another.

Polar of a Vertical Aerial.—A vertical transmitting or receiving aerial has a polar as in Fig. 46, that is to say, the polar curve of a vertical aerial is a system of concentric circles with their centres at the aerial.

Polar of a Frame or Loop Aerial.—This can best be understood by considering the E.M.F. generated in a frame by a wave coming in a constant direction, and by rotating the frame about a vertical axis.

Imagine a plan of the frame shown in Fig. 41 and a wave front cutting it as shown in Fig. 47.

It has previously been shown that in the position AB the frame is cut by a maximum number of lines of magnetic force, and a maximum E.M.F. is therefore generated in it. This is the position illustrated in Fig. 41. It was also shown that in position A^1B^1, where the frame is in the direction of the lines of force, and no lines of force cutting it, the E.M.F. generated in the frame is zero. Now consider the intermediate positions A^2B^2, A^3B^3, A^4B^4, etc. In position A^2B^2 the E.M.F. generated is obviously less than in the position AB, but greater than in the position A^1B^1, as fewer lines of force cut the frame at position A^2B^2 than at position AB, and more than at position A^1B^1.

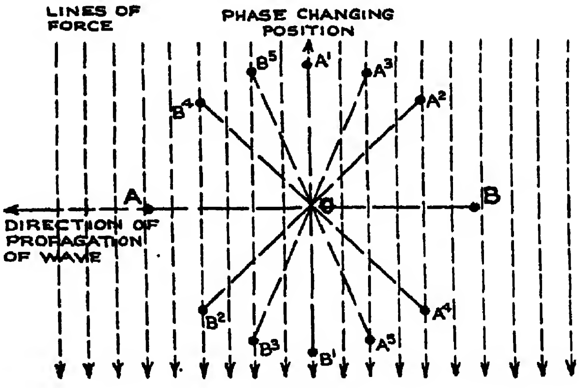

FIG. 47.

In position A^3B^3 there are less lines cutting the frame than at the position A^2B^2, but more than at A^1B^1, so that the E.M.F. generated is less than at position A^2B^2, but greater than at position A^1B^1, i.e. greater than zero.

Now consider position A^4B^4. Here the same number of lines pass through the frame as in position A^2B^2, since angle A^1OA^2 = angle A^1OB^4, and consequently an E.M.F. of the same magnitude is generated in the two positions. There is, however, an important difference.

In the position A^2B^2 the lines of force cut the conductor A^2 before they cut B^2, and produce an E.M.F. in one direction, while at the position A^4B^4 the lines of force cut the conductor B^4 before A^4, and produce the E.M.F. in exactly the opposite direction.

Thus is seen the very important fact that in passing through zero position A^1B^1 the phase of the E.M.F. generated in the frame has changed 180°.

Polar of a Frame Aerial (Figure Eight Polar).—The resultant polar of this frame aerial assumes a shape similar to that shown in Fig. 48. This is commonly called the figure eight polar.

The reader is strongly recommended to make himself thoroughly familiar with this curve, as it is on this that the whole science of the single rotating frame Direction Finder is based.

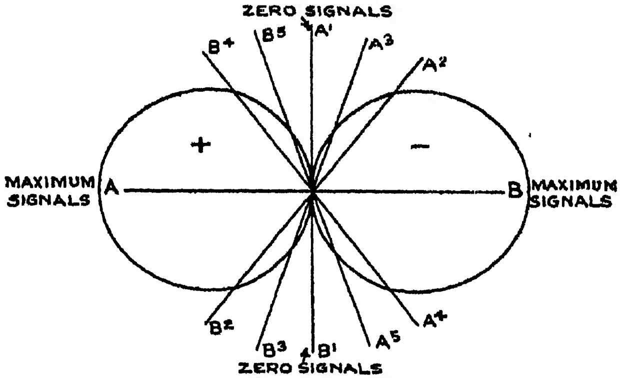

FIG. 48.

The curve demonstrates the following important facts :—

(1) On rotating a frame aerial through 360° on a given incoming wave front, there are two positions of minimum or zero signal strength, and two positions of maximum signal strength.

(2) The positions of zero signal strength are exactly 180° apart. One zero is called the "reciprocal" of the other.

(3) The positions of maximum signal strength are exactly 180° apart. One maximum is called the "reciprocal" of the other.

(4) The rate of change of signal strength in going through the zero position is much more rapid than when going through the maximum position, and consequently a system based on reading zero signals—in preference

to maximum signals—is more sensitive to the ear, and "swing bearings" can be taken on a much smaller arc than in a "maximum" system.

(5) In going through the position of zero signals, the phase of the E.M.F. generated in the frame changes 180°.

Effect of Earthing a Frame Aerial (Frame Vertical Effect).—Fig. 41 showed that when a frame aerial is insulated from earth, an E.M.F. is generated in each conductor (or system of conductors) AB and CD. In the position depicted the two E.M.F.'s each travel around the frame in opposite directions and cancel one another.

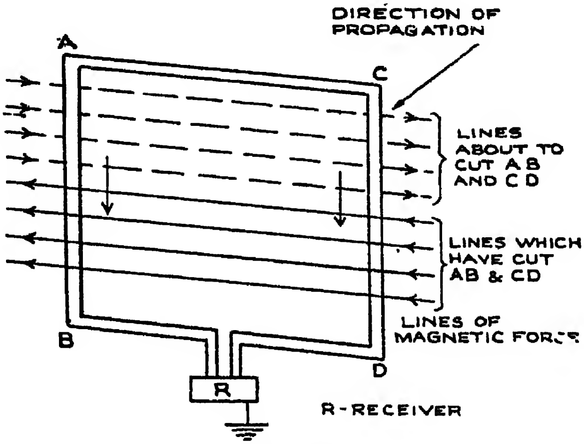

FIG. 49.

Now consider Fig. 49. Here the frame is earthed. This is a condition always present in a D.F. receiving system because, even if the frame is not directly earthed, the amplifying system connected to the frame is either earthed directly on the negative terminal of the low-tension battery, or else the capacity of the battery system to earth forms an earthing path for the current generated in the frame.

Now the two component E.M.F.'s in conductors AB and CD both pass to earth. If a receiver (R) be inserted in the earth lead, signals can be detected. In this position the signals received are due to the frame acting as two vertical aerials AB and CD joined through the receiver R to earth. This effect is a maximum in the zero position of the frame. Moreover, this

effect varies with the angle between the plane of the frame and the direction of travel of the wave front. Consider the other extreme case, i.e. where maximum signals occur on the frame as in Fig. 42. In this case the components of E.M.F. induced in the system of conductors AB and CD are such that they act together in the same direction around the frame. Thus the vertical effect due to the frame itself is a minimum when the frame reception is a maximum.

In other words, the *polar of the vertical effect due to the frame itself* is an effect capable of rotation, and is a maximum

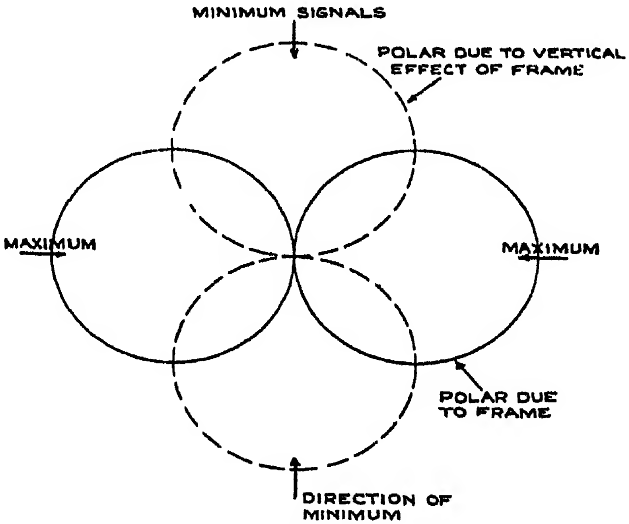

FIG. 50.

when the frame is in the zero position for incoming signals, and *vice versa.* Thus the true polar of the frame is not exactly as shown in Fig. 48, but as shown in Fig. 50.

Direct Vertical Effects.—Moreover, considering the whole system from the frame windings themselves right through to the telephones, there are additional effects to be taken into consideration.

Usually, from the frame windings to the receiver there is a system of wires which does not rotate. These wires are screened and the screen earthed. Also, there is a certain amount of energy which is picked up in the receiver, and even in the telephone leads.

All these various conductors, which are essential to the D.F. system, are liable to pick up direct energy from the incoming wave. To minimise this direct pick-up of energy as much as possible, elaborate screening of the leads from the frame windings to the receiver, and of all the components of the receiver itself, are resorted to, but despite all precautions it is almost impossible to avoid energy getting directly into the set. This produces yet another polar which, however, is not capable of rotation as the one shown in Fig. 50, but is simply a circular polar. Thus the *complete* polar diagram of a frame system is as shown in Fig. 51.

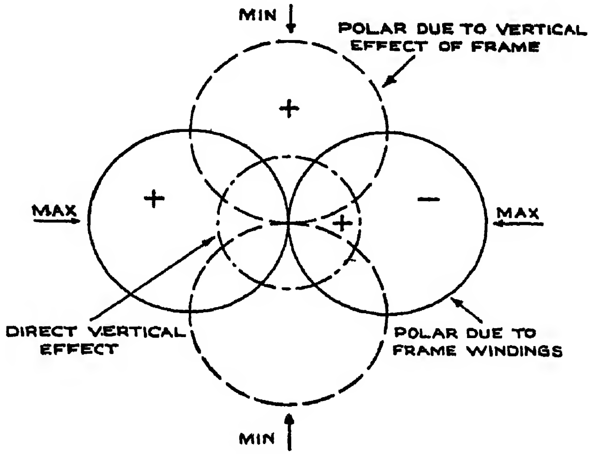

Fig. 51.

It should be noted that the further the frame windings are from the receiving system the more will the installation be liable to the direct vertical effect, and the greater will be the screening precautions necessary to minimise this effect.

Summation of Vertical Effects.—There are, as previously shown, two vertical effects to consider :—

(1) That due to the properties of any frame system. This effect is capable of rotation.

(2) That due to the direct pick-up of energy in the receiving system, other than the actual energy received in the frame. This vertical effect is not capable of rotation.

If these two vertical effects are superimposed on one another, results are as shown in Fig. 52.

Figs. 52B and 52C are the resultant polars of Fig. 52A dependent upon the phase of the direct vertical relative to the phase of the frame vertical.

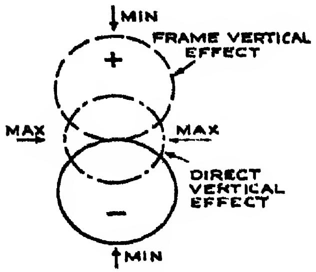

FIG. 52A.

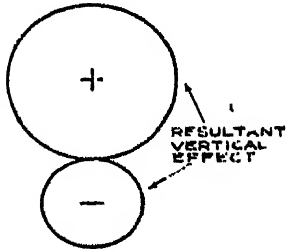

FIG. 52B.

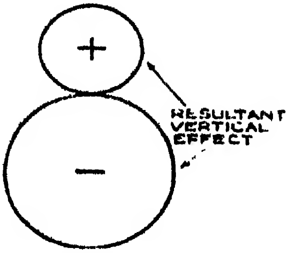

FIG. 52C.

Added Vertical Effect.—It is to be noted that such a polar (i.e. one consisting of a positive and negative effect) is not an easy one to work with, especially if one ultimately wishes to work with relative phases. To do this, the small circles marked — in Fig. 52B, and + in Fig. 52C, must be entirely eliminated. Imagine this to be done by introducing an equal and opposite vertical into the set, thus obtaining polars as shown in Figs. 53A and 53B.

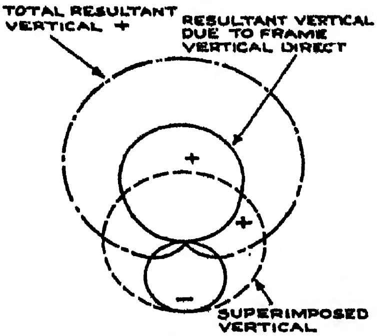

FIG. 53A.

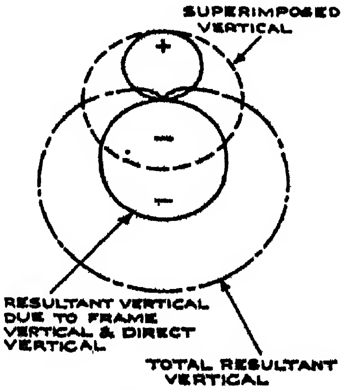

FIG. 53B.

In a system in which the polar corresponds either to Fig. 53A or Fig. 53B, the induced E.M.F. due to the vertical is either entirely positive or entirely negative. This is easier to work with, and can be used when it is desired to work purely with phases.

Result of Vertical Effects on Bearings.—In the ideal case of a frame in which there is absolutely no vertical, the result is as shown in Fig. 54.

There are two minima X and Y exactly opposite one another, i.e. at 180° apart, and one bearing would be the exact reciprocal of the other.

With added uncorrected vertical effect the minima occur at X^1 and Y^1, which are not exactly 180° apart. Depending on the details of the installation, the angular displacement of X^1 and Y^1 from their true positions may be anything up to 20°.

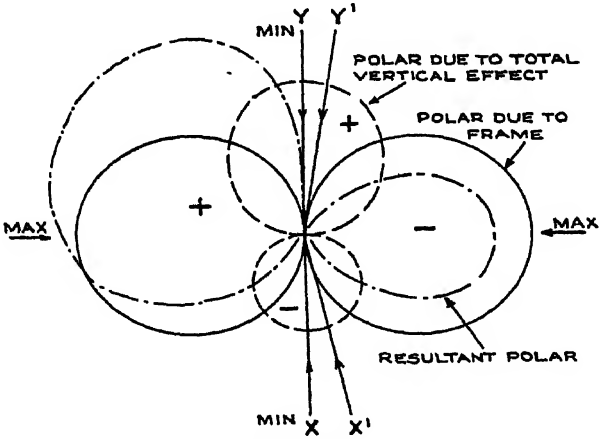

Fig. 54.

The average displacement in practice is 2° or 3°. The maxima are unequal in strength.

Also, the " angle of swing " around the zero position is broad.

Result of Compensated Vertical Effect on Bearings.—Consider the effect of the compensated vertical on bearings. In this case the resultant polar of the two vertical effects is shown in Figs. 55A and 55B superimposed on the true frame polar. It will be observed that there is a true and sharp minimum either in the true direction or in the reciprocal position to the true direction depending on the phase of the compensated vertical polar relative to the frame polar. Complementary with this true and sharp minimum there also occurs a false and woolly minimum. This false minimum is ignored, and thus by using a compensated vertical effect one can obtain—

(1) A sharp minimum.
(2) A true direction minimum.

This result should be compared with that shown in Fig. 54 where, owing to a vertical effect which is not compensated for, minima are obtained which are neither true, nor accurate, nor

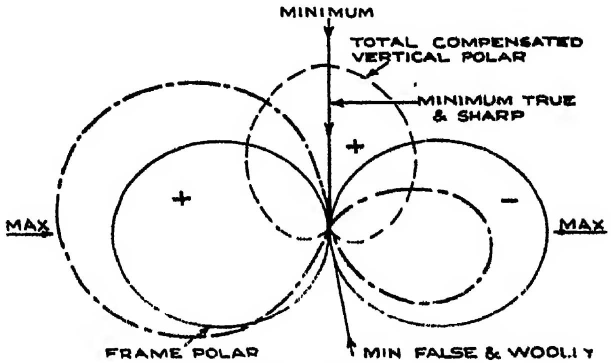

FIG. 55A.

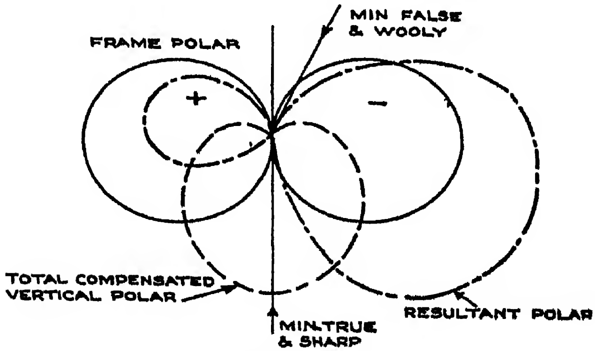

FIG. 55B.

sharp. In many cases where the vertical effect is not compensated for a very large angle of swing, e.g. 40°-60°, may be required to obtain a bearing.

Determination of "Sense" or True Direction.—If a bearing on a station is given as 20°, this implies that the station is on a line 20° east of true north. This is exactly the same line of bearing as 180° + 20° = 200°. Thus, if a bearing is taken on an unknown ship, an ambiguity would arise as to whether the unknown ship were 20° on the starboard bow or 20° on the port quarter, assuming the ship's head to be pointing

due north. In foggy weather, when there is a danger of collision, it is vital to know the true direction of the unknown ship.

This determination of the true direction (20° in the above example) is what is known as the determination of *true direction* or "*sense*" of a bearing.

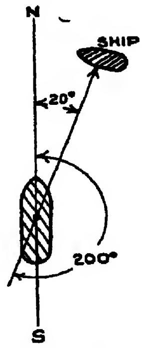

FIG. 56.

To Determine the "Sense" or True Direction (Heart-shaped Diagram).—From the polar curve of a frame aerial it is possible to obtain two maxima and two minima on any bearing, and under ideal conditions each maxima and minima is separated by 180° from the other corresponding point.

Consider the case represented in Figs. 57A and 57B. Here the frame AC is in the plane joining the positions of the transmitter and the receiver, i.e. in the position of maximum signals.

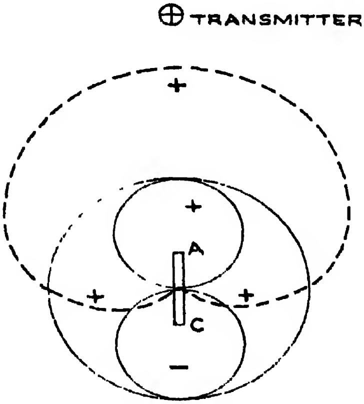

FIG. 57A.

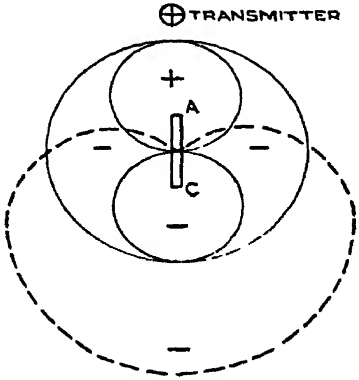

FIG. 57B.

This gives the *figure eight* polar, of which one-half is positive and the other half negative (*vide* Fig. 48).

Now consider a second polar from a vertical aerial superimposed upon this figure eight diagram as indicated in Fig. 57A. This second polar is assumed to be positive in sign. The resultant polar is as shown dotted.

If the vertical aerial polar is negative in sign, the resultant polar is as shown in Fig. 57B.

By this arrangement the *true direction* or "*sense*" of the transmitting station is obtained.

Fig. 57A represents the superimposition of the polar curves working on maximum signals, while Fig. 57B gives the result working on minimum signals.

As the ear is more sensitive to minimum signals than to maximum signals, it is best to work on the conditions illustrated in Fig. 57B. This type of diagram is commonly called the *heart-shaped diagram* or *cardiac diagram*.

Conditions for obtaining "Sense" or True Direction.—The conditions which must be fulfilled for the determination of "sense" or true direction are—

(1) The frame must point *in the direction* of the transmitting station, i.e. it must be in the position of maximum signals.

(2) The currents in the frame aerial and vertical aerial must be in the same direction for one frame maximum, and in the opposite direction for the other frame maximum. This condition is fulfilled when the frame and vertical aerials are *in tune* with one another.

(3) The *amplitude* of the current from the vertical aerial must equal the *amplitude* of the current in the frame.

CHAPTER IV.

RÉSUMÉ OF DIRECTION FINDING.

Direction-finding stations may be classed under two headings—

(*a*) *Directional transmitters.*
(*b*) ,, *receivers.*

In marine work (*b*) may be further classed under the headings—

(1) Shore stations which give ships their bearings.
(2) Ship D.F. sets which take bearings on known ship or shore stations.

Advantages and Disadvantages of Transmitting D.F. Stations :—

Stations of this type possess the advantage that any number of receiving stations (which need not be of a special D.F. nature) can receive bearings at the same time. The drawbacks of stations of this type are :—

(1) They must be almost continuously transmitting to be of value, and they consequently cause jamming. The ether is already overcrowded in waters where D.F. is most essential.
(2) The accuracy of bearings from stations of this type is not great enough to be of use to the navigator except at very short ranges.

Advantages and Disadvantages of Shore D.F. Stations :—

D.F. receiving stations on shore are exceptionally useful and of considerable use to navigators. They have the following important advantages :—

(1) They can be installed with the utmost care and accurately calibrated.
(2) They are always working under ideal conditions of reception.

Their chief drawbacks are :—

(1) They cannot deal with more than one ship at a time, although a number of ships may require bearings from a coastal D.F. station at once. This is especially the case in fog when ships require frequent information regarding their positions.

(2) They are liable to coastal reflection and refraction (see Chapter X.).

Advantages and Disadvantages of Ship D.F. Stations :—

D.F. Receiving Stations on Ships.—These are probably the most useful aid to navigation. They have the following great advantages :—

(1) Bearings can be taken at any time the navigator requires them, provided they are within D.F. range of shore stations or another ship whose position is known. This is particularly valuable in fog when the ship not only requires its own position, but also that of other ships it wishes to avoid. Further, a ship fitted with D.F. can not only receive an S.O.S. call, but can orient the position of that call, and so be a valuable aid to safety of life at sea.

(2) Very great accuracy is assured provided the D.F. set is properly installed, calibrated, and handled. Accuracy to within 1° at 300 nautical miles is attainable, and greatest accuracy is obtainable within shorter (navigating) ranges. On a properly installed D.F. receiver the accuracy should be at least within 0·5° at 50-60 miles on a normal coast station, and this accuracy should increase with decreasing distance between the transmitter and the D.F. set. It should be clearly understood that a D.F. set is, under normal conditions, a precision instrument, and, if properly installed and used, is correspondingly accurate. Should there be discrepancies between bearings obtained by W/T and other methods respectively, those obtained by W/T are more likely to be accurate — subject always to " night effect " errors, the presence of which can be detected.

The only real check on the accuracy of a D.F. set

is by means of *visual* observations, carried out in daytime. Experience has shown that errors wrongfully alleged to be inherent in the D.F. system, have been due to :—

(*a*) Poor observations (parallax errors in reading); (*b*) personal errors of the observer; (*c*) inexperience on the part of the visual observer; and (*d*) inaccurate methods of observation.

With reference to (*d*), this is particularly the case in checking bearings on a D.F. set against visual bearings, using a magnetic compass fitted with an azimuth on a rolling ship. It frequently happens, owing to the rolling ship and the inertia of the compass card, that the compass is much slower in following a change in the ship's course than the D.F. set, and errors of 0·5°-1·0° can easily arise in this manner.

The following may be considered as the disadvantages of this system :—

(1) Conditions at sea are not always ideal for the taking of bearings; in fact, ideal conditions are of rare occurrence.

(2) Lack of liaison between the navigators and the W/T operators. This can only be remedied by close co-operation between the W/T room and the Bridge. It seems strange that navigating officers are frequently prone to place greater reliance on a shore D.F., where the personnel is an unknown factor, than on the set and personnel under their own control.

It should be remembered that under any of the above systems—whether they be D.F. transmission or reception systems—there is always the drawback of "night effect" (see Chapter X.). If, however, the type of D.F. set installed will indicate the presence of "night effect" on bearings, then the operator is always in a position to know whether the bearings may be considered as reliable or otherwise (see Chapter IV., p. 72).

Directional Transmission.—One of the oldest types of directional transmitter was the *Telefunken Compass,* now obsolete.

This consisted originally of thirty-two aerials arranged in a

circle around a central transmitting plant. Each aerial corresponded to a point in the magnetic compass.

The transmitter was so arranged that the aerials were connected in turn for one second to the transmitter. Thus in 32 seconds signals were sent out by 32 different aerials, each representing a point on the magnetic compass.

Before the rotary transmission commenced, a warning signal was sent on an umbrella or non-directional aerial. Then followed the rotary transmission commencing on the north-south aerial pairs, and proceeding from north to east and south. Ships wishing to employ this system could do so by using their normal ships receiving installation. The operator was equipped

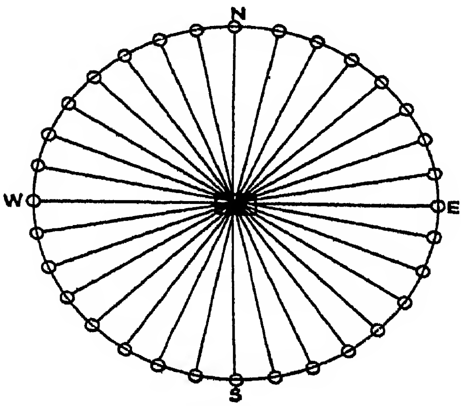

Fig. 58a.

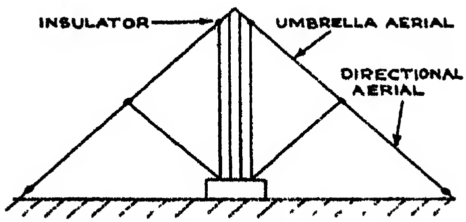

Fig. 58b.

with a special compass stop-watch, which was so constructed that it made a complete circle in the same time as the transmitter contacts on to the various aerials, i.e. it ran in synchronism with the transmitter rotary contacts on to the aerials.

A ship wishing to obtain its bearing proceeded as follows: The operator heard the warning signal and then started his watch as this signal ceased. In the position of minimum signals the watch was stopped. The reading of the watch hand gave the bearing of the ship relative to the transmitting station. Usually this system was worked in pairs of transmitters as illustrated in Fig. 59.

Bearings were taken on the transmitters A and B from the ship S, and the point of intersection of these bearings gave the position of the ship.

This system has many drawbacks, the chief being :—

(*a*) Difficulty of obtaining suitable sites for such large aerial systems, and of achieving the same conditions of earth resistance for all aerial pairs.

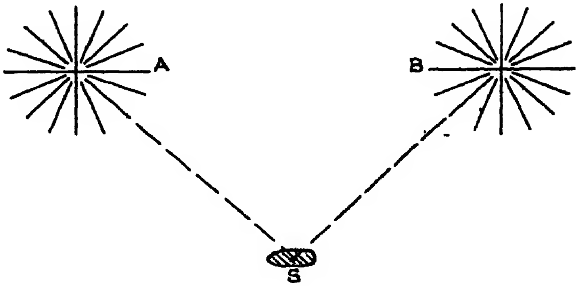

Fig. 59.

(*b*) The impossibility of running the watches at the receiver end accurately in synchronism with the transmitter rotation period. The result was that only approximate accuracy, i.e. within 5°-6°, could be obtained.

This system was further elaborated for the use of German aircraft, ninety pairs of aerials being used. By this means greater accuracy was obtainable, but only within 2°-3°.

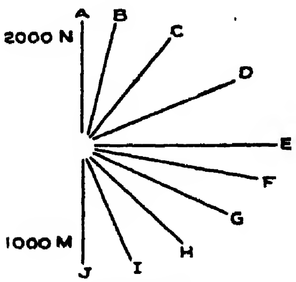

Fig. 60A.

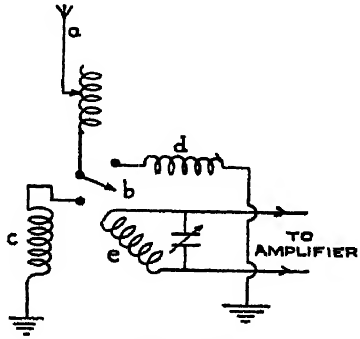

Fig. 60B.

A system of directional transmission using multiple aerials was developed by Robinson in England for use with aircraft. Here again the degree of accuracy is not very high. Robinson's arrangement consisted of a system of aerials as represented in Fig. 60A,

The wave-length is a variable function and varies with direction. The operator tunes in to the incoming signal and observes which signals are weakest.

The transmitter sends, say, signal A on aerial A, signal B on aerial B, and so on, and the operator, say, hears the two minimum signals C and D.

The receiving end is shown in Fig. 60B. It consists of an aerial system (*a*) and a choice of earth coils (*c*) and (*d*), which can be alternately joined in circuit through switch (*b*); (*e*) is a coupling coil to (*c*) and (*d*), and is connected to an amplifying system. When the operator hears minimums on signals C and D from the transmitter, he listens for C by connecting switch (*b*) to coil (*c*) and to D by connecting switch (*b*) to coil (*d*).

He adjusts the coupling coil (*e*) until the strengths of signals C and D are equal.

Knowing the relation of the coupling of coil (*e*) to coils (*c*) and (*d*), it is possible to calculate the actual direction of minimum transmissions between C and D.

Marconi Beam Transmitter.—The Marconi Company has developed a method in which a system of reflectors causes a rotary beam to be transmitted. Such a system has been installed and worked at Inchkeith.

The system consists of two ½ K.W. spark transmitters arranged at the foci of two rotating parabolic reflectors, the apertures of which are 13 metres. This whole system is caused to rotate mechanically once in two minutes, so that a ship fitted with a suitable receiver comes into the line of maximum signals once a minute.

Automatic transmission is used, and Morse letters are sent out as either reflector faces a specific direction. A bearing is taken as follows:—

The operator, or navigating officer, taking the bearing, listens in on the special receiver, and after a few seconds hears a faint Morse signal, then a louder signal, and still a louder one, followed by two signals getting fainter in strength. Then, by decreasing the sensitivity of the receiver, he " brackets " the signals till he hears only three signals, the centre one being the loudest. This signal is read, and as a definite Morse letter represents a specific direction relative to true north, it is possible to read the bearing of the ship relative to Inchkeith.

The beam is so narrow that on maximum signal strength at the receiving station the direction can be determined with fair accuracy. The advantages of this system are :—

(*a*) Freedom from interference by other W/T stations ; and

(*b*) freedom from atmospherics owing to the short wave-length employed.

The disadvantage of the system lies in the fact that only short waves of about 6·3 metres can be used, because the reflector screens must be of the same order as the waves transmitted, and the system is therefore limited by the size of the screen reflectors which can be conveniently built.

The range of this system is very limited (up to about 10 miles).

At the receiving ship two separate aerials are necessary, one on the port side and the other on the starboard side, as the waves are deflected by the metal mass of the ship.

A detailed description of the apparatus employed at Inchkeith station using this system was published in the " Wireless World " of 25th March, 1925.

Directional Receiver Systems.—D.F. receivers may be divided into two main types :—

(1) *Two-frame systems.*
(2) *Single rotary-frame systems.*

In the first category falls the well-known Bellini-Tosi system which has been very fully developed by the Marconi Company, and is known as the *Marconi-Bellini-Tosi* system (M.B.T.). It works on positions of minimum signals, i.e. the direction from which minimum signals are received in the receiver is the direction of the incoming wave.

In this category is also included the *Robinson* or *Cranwell system*, which was developed essentially for use in aircraft. This system works on positions of maximum signals.

In the second category fall the following :—

The *Kolster* and *Dunmore system* (used chiefly in the United States), the *Bellini system*, and the *Siemens system*, all of which work on " minimum " signals.

Comparison between Maximum and Minimum Methods of D.F. Reception.—Consider a coil as in Fig. 61.

If the axis XOY represents the direction of the incoming

signal, MON the frame rotating on the axis O, and θ the angle which the frame makes with the direction of the incoming wave-front, then the energy induced into the frame is represented by

$$OP = OM \cos \theta ;$$

or, if e is the energy induced in the coil, then

$$e = E \cos \theta,$$

where E is a constant dependent on the dimensions of the coil.

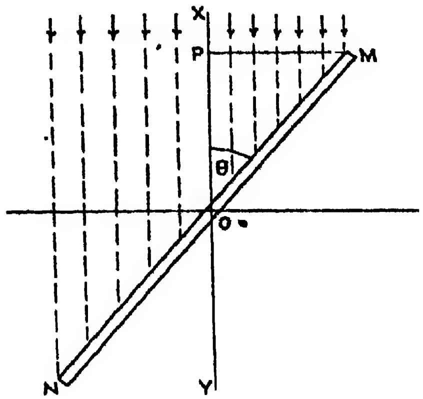

FIG. 61.

Thus, in the position of maximum signals, the variation of the energy is proportional to the cosine of the angle between the frame and the direction of the incoming wave.

In the position of minimum signals, the variation of signal strength is proportional to sin θ.

Now, the sine of an angle changes rapidly near 0°, while the cosine changes slowly through 0°, so that a small movement on the minimum method gives a big change in signal strength compared with a corresponding change on the maximum method. This makes the minimum method more sensitive for taking bearings than the maximum method.

The maximum method has, however, the following advantages :—

(1) Signals can be read whilst the bearing is being taken.
(2) Greater ranges can be worked.
(3) Extraneous noises do not interfere so much with the taking of bearings.

Under suitable conditions, i.e. where interference from external noises is not important, the minimum system is of advantage.

In aircraft, on the other hand, where the engine noises are very loud, a maximum system can be used with advantage.

Two Coil System (M.B.T.).—This system consists of two aerials at right angles to one another. For ship work, one

aerial is arranged on the fore and aft line of the ship, and the other athwart ship. As the ship itself acts as an aerial, it is arranged that the area of the fore and aft aerial is less than that of the athwart ship aerial.

These aerials are fixed and calibrated. They are led into an instrument comprising two coils, which may be looked upon as the duplicate of the large outside aerials, and produce fields proportional to the energy induced by the incoming wave on the outside aerials.

Rotating inside these coils is a third coil called the search coil. This portion of the receiver, consisting of the coupling coils and the search coil, is called the *radiogoniometer*.

A diagrammatic illustration of this system is given in Fig. 62.

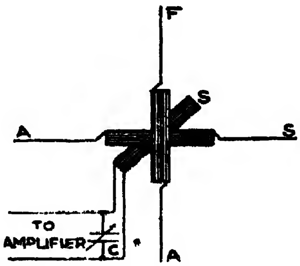

FIG. 62.

F.A. = Fore and aft aerial.
A.S. = Athwart ships „
S. = Search coil.
C. = Tuning condenser.

The aerials on ship work are aperiodic (i.e. not tuned). On land installations, especially for long range work, the aerials are frequently tuned to the incoming signal.

Imagine an incident wave to fall upon an aerial system such as shown in Fig. 63A.

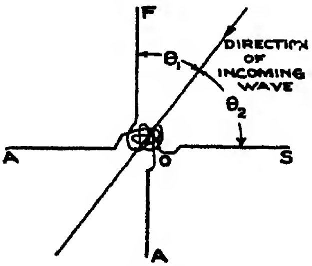

FIG. 63A.

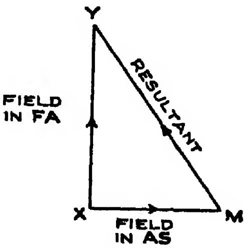

FIG. 63B.

The currents induced in aerial FA will depend upon cos θ_1, and the magnetic field set up by these currents will also vary as cos θ_1. This field will act along the axis of FA, i.e. along AS.

Also, the magnetic field set up by the currents induced in aerial AS will be proportional to cos θ_2(= sin θ_1), and this will be at right angles to AS, i.e. in direction FA.

These magnetic fields are shown in Fig. 63B, the resultant field being YM.

It is seen that the position for maximum signals is at right angles to the direction of the incoming wave front. In actual practice the set is made to work on the position of minimum signals. Usually, one works by matching the strength of signals on either side of the minimum position. The *angle of swing* on good bearings on ship installations is between 20° and 30°.

In the older types of M.B.T. sets, the athwart ship aerial usually consisted of a single loop whose area was about 120 sq. ft. The fore and aft aerial was of smaller area.

In the later pattern the single outside fixed loops have been replaced by a fixed framework consisting of two sets of loops at right angles to one another. These loops have about five turns each, and are so situated that the loop bases are about 4 ft. from the deck.

The loops are approximately 8 ft. high and 4½ ft. square.

To obtain equal range to that given by installations employing a large aerial, an additional amplifying valve has been added to the receiver.

Robinson or Cranwell System.—This is essentially a system designed for use with aircraft.

Owing to extraneous noises of engines, etc., it is a very difficult matter to receive on minimum signals. This is due to the fact that on minimum signals bearings are, as a rule, determined by matching signal strength on either side of a minimum. If noises or jamming occur, or these noises are at all directional relative to the frame, it is almost impossible to take an accurate bearing by matching signal strength on either side of a minimum. Moreover, in aircraft it is frequently essential to read the signal at the same time as the bearing is taken.

In the Robinson system, use is made of two frames at right angles to one another. These frames—usually called the *main* and *auxiliary* frames—are rotatable together, i.e. always at 90° relative to one another, about a central axis.

The general idea of the system may be gathered from Fig. 64.

Method of Working.—The method used is to get the main coil M in series with the balancing coil E roughly into the posi-

tion of maximum signal strength. The auxiliary coil A is then brought into action by means of the changeover switch X.

Imagine the main coil M not to be exactly in the plane of the incoming signal; then the auxiliary coil A will not be exactly at right angles to the direction of the incoming signal, and will consequently pick up a certain amount of energy. This auxiliary coil A is so connected up that by means of a reversing switch Y, the energy induced in A by the incoming wave is made to help that induced in M in one direction and so strengthen signals, and to oppose that in M in the other direction, and so weaken signals. Thus, if coil A picks up any

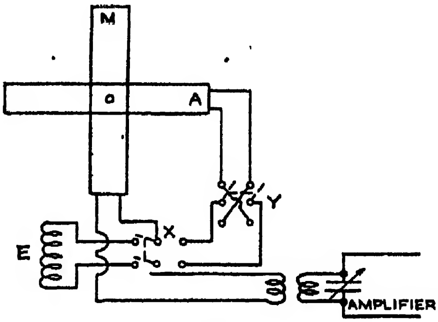

Fig. 64.

M represents the main coil. } These coils rotate together about the
A ,, ,, auxiliary coil. } common axis O.
E ,, ,, balancing coil of the same inductance value as M.
X and Y are change-over switches.
X is for the purpose of switching either the auxiliary coil A or the balancing coil E in series with the main coil M.

energy, i.e. if coil M is not pointing towards the transmitting station, any reversal of switch Y will affect the strength of signals received. If reversing the switch Y produces no change in signal strength in the amplifier, then the auxiliary coil A is at right angles to the direction of the incoming signal, and the coil M is in the plane of the incoming signal, and the bearing of M is the bearing of the transmitting station.

Theory of Robinson System.—Let AA_1 and BB_1 be the two fixed coils at right angles to one another and capable of rotation about O, as shown in Fig. 65. If OP be the direction of the incident wave, forming an angle with coil AA_1, then the E.M.F.'s induced in the coils are :—

$$e_1 = E_1 \cos\theta,$$
$$e_2 = E_2 \sin\theta,$$

where E_1 and E_2 are constants depending on the dimensions of the coils. Only portions of these E.M.F.'s e_1 and e_2, say, k_1 and k_2, reach the amplifier.

If $\quad e_3 =$ resultant E.M.F. in receiver,

then $\quad e_3 = k_1E_1 \cos\theta + k_2E_2 \sin\theta.$

The rate of variation of e_3 with respect to θ is given by

$$\frac{de_3}{d\theta} = - k_1E_1 \sin\theta - k_2E_2 \cos\theta.$$

For small values of θ, this quantity becomes approximately

$$- k_2E_2 \cos\theta.$$

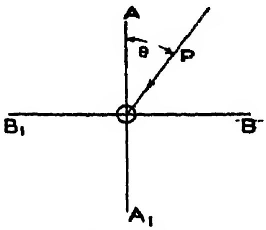

FIG. 65.

The amplitude of this variation can be adjusted by fixing a suitable value for k_2E_2, i.e. from the constants of the auxiliary coil and the coupling. Thus the E.M.F. introduced by switching in the auxiliary coil can be chosen at any convenient value.

Also, the ratio $\frac{k_2E_2}{k_1E_1}$ depends on the number of turns in each coil multiplied by its area, and on the fraction of this E.M.F. which is effective in the receiver. The E.M.F. produced in the receiver is dependent on the area turns of the coil. Hence it is advisable to increase the area turns as much as possible. This, however, is limited by the following factors :—

(1) Self-inductance of the coils.
(2) Self-capacity of the coils.

To minimise these two factors, the coils are wound so that there is a spacing of about 1 in. between turns.

It is usual in practice to wind the auxiliary coil with a bigger value than the main coil in the ratio of about 4 : 1.

It is obvious from a study of this method that an ambiguity of 90° may occur. This may be due to imagining that the main coil was in the position of maximum signal strength, when in reality the auxiliary coil was in that position, and the

reversal was due to the energy in the main coil affecting that in the auxiliary coil.

This chance of ambiguity is entirely eliminated in the latest pattern in the following way:—

There are obviously two positions where the main coil E.M.F.'s will equal those of the auxiliary coil, so that on a reversal one would obtain zero signals. These positions will be on either side of the true maximum position of the main coil.

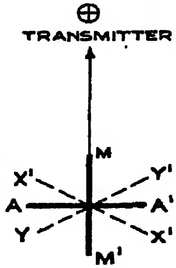

FIG. 66.

In positions XX^1 and YY^1 (Fig. 66) the signal strength would be zero.

In the newer types of set the changeover switch X and the balancing coil E (Fig. 64) are eliminated. The main and auxiliary coils M and A are rotated together, and are continuously in circuit. While the coils are being rotated, the switch Y is operated and the two positions of weakest signals noted.

The mean of these two positions gives the direction of the incoming wave. It will be noted that in this position the main coil M gives maximum signal strength, and thus the signals can be read.

SINGLE-FRAME SYSTEMS.

Advantages and Disadvantages.—It was shown (Chapter III.) that the polar of a single rotary frame is a figure-eight diagram. Numerous D.F. sets have been devised on these lines with a fair amount of success. During the war an efficient single-frame set was devised for the location of enemy aircraft. As these machines were always operating within fixed areas, great accuracy was not required, and good approximate bearings were obtained. The disadvantages, however, of a single-frame aerial are obvious:—

(1) To get any strength of signal into the telephones, a fairly large value of area turns is required in the frame. This necessitates an unwieldy frame from a mechanical point of view.

Provided the frame is made small enough to be mechanically easy to operate, then the energy received is necessarily small, and a big amplification is required

to bring up the signal strength. Provided that an amplifier is designed for this purpose, then there is the great difficulty of keeping the "direct effect" due to the amplifier within small enough limits to prevent the amplifier from bursting into oscillation, and also to prevent the frame from acting as a direct vertical.

(2) A single-frame set must be calibrated accurately before it is any use for D.F. purposes.

The advantages of a single frame, provided it can be used, are many :—

(1) It is an ideal form of reception and absolutely symmetrical. Thus, one does not encounter the secondary effects inherent in multiple frames where there is the interaction of frame upon frame to be considered.

(2) One knows exactly what is happening as regards wavelength, amplitude, and especially phase.

(3) The single frame used in conjunction with a vertical receiving aerial gives an ideal method of obtaining the "sense" or true direction of the bearing without any possible chance of error.

(4) The single-frame method is equally efficient for the reception of spark, C.W. or I.C.W. signals, and there is no change in the C.W. note in passing through the minimum. This is difficult to achieve with multiple frames owing to interaction between frames.

(5) A single frame set can be designed to take up a minimum of space, which is valuable on a ship.

(6) A single frame can be so designed that it can be dismantled and erected in a few minutes without necessitating recalibration. This in itself is a great advantage for ship work, especially if a ship is coaling, or if, in the case of a warship, the decks are cleared for action.

Thus, provided a single frame can be suitably designed, it possesses many advantages over other means. Everything depends on—

(*a*) Mechanical design.
(*b*) Electrical design to eliminate vertical effects.
(*c*) Calibration.

(*a*) Can be achieved by suitable attention to requirements and detail; (*b*) can be achieved by suitable screening methods, and by the use of a vertical effect equal and opposite to that due to the frame and the direct reception; (*c*) can be carried out by suitable arrangements once the set has been properly installed.

Kolster and Dunmore System.—This system has been developed by the U.S.A. Bureau of Standards, and is used both on war vessels and in the American mercantile marine.

It employs a single rotating square frame aerial 4 ft. × 4 ft. with eleven turns of wire, and mechanically so designed that the frame rotates over a standard magnetic compass. Thus bearings are read relatively to magnetic north.

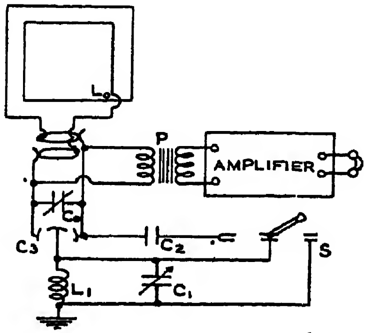

Fig. 67.

From Fig. 67 it will be observed that the circuit consists of a frame L_0, which is tuned to the incoming wave-length by means of the variable condenser C_0. Across this condenser C_0, connected either directly or through a transformer P, is the amplifier. The latter consists of three high-frequency stages, a detector and two stages of low-frequency amplification, the whole unit being designed with a minimum of operating adjustments.

The auxiliary circuits of the set are controlled by means of switch S. When this switch is to the right, then the central plates of the condenser C_3 are directly earthed. This double condenser is used to obtain electrical symmetry of the coil system relative to earth. In other words, by adjusting the central plates of the condenser C_3 either to the right or the left, the earth connection is brought to the electrical centre of the frame system. This means that the signal received in the telephones results only from the energy directly received in the coil L_0, i.e. reception is on the figure-eight loop system.

When the switch S is closed to the left, a small condenser C_2 is connected across half the double condenser C_3, and the inductance L_1 and the tuning condenser C_1 are inserted in the earth lead.

In this position the energy is picked up in the vertical aerial consisting of L_1C_1 and the capacity of the coil L_0 to earth. By proper adjustment of C_2 and the circuit L_1C_1 a complete unidirectional effect is obtained.

The *method of operation* is as follows :—

Switch S is closed to the right to obtain a bearing on a transmitting station, and to the left to obtain a "sense" or true direction of the station.

To take a bearing, the coil L_0 is tuned by means of C_0 to be in resonance with the incoming signals, and the frame rotated for minimum signals. In this position the frame is at right angles to the direction of the incoming wave front.

To obtain "sense" or true direction, the switch S is turned to the left, and by adjustment of C_2L_1 and C_1 the vertical is tuned to the wave-length of the incoming signals. Now, if the frame is rotated to the position of maximum signal strength, it will point towards the transmitting station whose true bearing is required.

Bellini System.—This is a single-frame system (see Fig. 68).

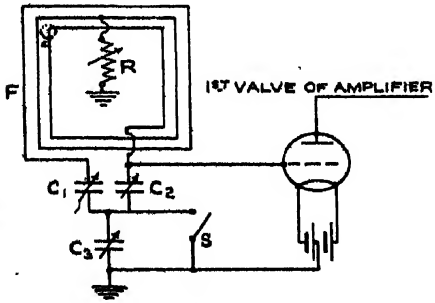

FIG. 68.

The frame circuit consists of a frame F and condensers C_1 and C_2.

The vertical aerial consists of the earthed centre of the frame F through a variable rheostat R, the capacity of the frame F, and the two condensers C_1 and C_2, which are earthed through the tuning condenser C_3.

When switch S is open, reception is effected on the vertical aerial, and the ordinary circular polar applies.

If switch S is closed, then the amplifier is connected directly across the frame, and reception is on the figure-eight diagram. To obtain a bearing, the switch S is closed and the frame tuned to the incoming signals. The false vertical effect of the frame is practically eliminated by earthing the centre point of the frame through the variable rheostat R. The sharpening of the minimum due to the elimination of the remaining vertical effect is accomplished by varying C_1 and C_2.

Fig. 69 —Siemens' D.F. frame.
With handwheel and pulleys.

[*To face page* 65.

To obtain " sense " or true direction, the switch S is opened and the vertical aerial tuned by means of the condenser C_3. By using the resistance R, it is possible to obtain the heart-shaped diagram.

Sharp bearings can only be obtained by careful use of condensers C_1 and C_2. Moreover, the valve damping across the frame is always present, and this limits the range and selectivity of the set. Actual tuning of the frame is accomplished by condensers.

The frame is square in shape, each side being 80 cms. long, and ten turns are wound for a wave-length of 300-1100 m. Slip rings are used to convey the energy from the frame to the amplifier.

For further details of this system the reader is referred to E. Bellini's paper in " L'Onde Electrique " for 1924.

Siemens' System.—This system makes use of a rotary frame (illustrated in Fig. 69) specially designed for ship-work.

In the design special attention has been paid to the following points :—

(1) Ease of fitting.
(2) Minimum space occupied.
(3) Maximum efficiency on figure-eight diagram reception, and efficient screening.
(4) Robustness.
(5) Watertightness.
(6) No obstruction to the field of view when visual observations are required.
(7) No influence on the magnetic compass.
(8) Ease of dismantling for coaling or other purposes ; and
(9) Flexibility of drive.

With regard to item (1), the frame is fitted by cutting an 8¼ in. circular hole through the deck and bolting the base plate to it by means of six brass bolts. The joint between base plate and deck is rendered watertight by a felt washer and white lead.

Regarding item (2), the loop of the frame has a diameter of about 3 ft., and the column is a strong brass casting about 4 ft. high. This column serves two purposes, viz. : (*a*) To raise the loop above normal deck structures, such as railings, etc. ; and (*b*) to prevent energy received in the loop from reacting on the

iron decks and causing re-radiation from the deck, and thus falsifying the direction of the bearings.

Concerning item (3), the frame windings are contained in a tubular ring of drawn brass, and the leads from the ring to the base of the frame are carried on fixed brass rods enclosed in the brass column. Thus all leads from the frame to the base of the column are carefully screened in a metal casing, which is earthed, and every precaution is taken to eliminate direct pick-up and consequent vertical effect between the loop and the base of the column.

As regards item (4), the whole structure is a stout brass casting which will withstand normal handling without fear of damaging any of the electrical portions of the frame.

Regarding item (5), the frame and column and base are all fitted together in an absolutely watertight manner, so that even with the frame immersed in water the windings remain unaffected by wet or moisture.

Concerning item (6), it frequently happens that the frame has to be erected in a position where visual observations for navigation purposes are taken, e.g. on the standard compass platform. Consequently, no object which would obstruct the field of view of the observing officer is permissible. In this type of frame the ring is only about 3 in. thick, and as it is moreover rotatable, the visibility is not affected.

With respect to item (7), it is essential that the frame and column—if erected near the standard magnetic compass—should in no way influence the calibration of this instrument. In order to permit of the D.F. frame being erected, if necessary, in very close proximity to the standard magnetic compass, the whole of the metal work of the frame ring and column is made of brass.

With reference to item (8), when a frame has to be erected in such a position that it is liable to be damaged during lowering, a frame of special design is used so that the loop and column may be removed and dismantled in a few seconds. A waterproof cap is then fitted on the frame base, and protects it from any damage when the frame and column have been removed. The frame can be set up in a few seconds. It is impossible to fit the frame and column to the frame base in a wrong position.

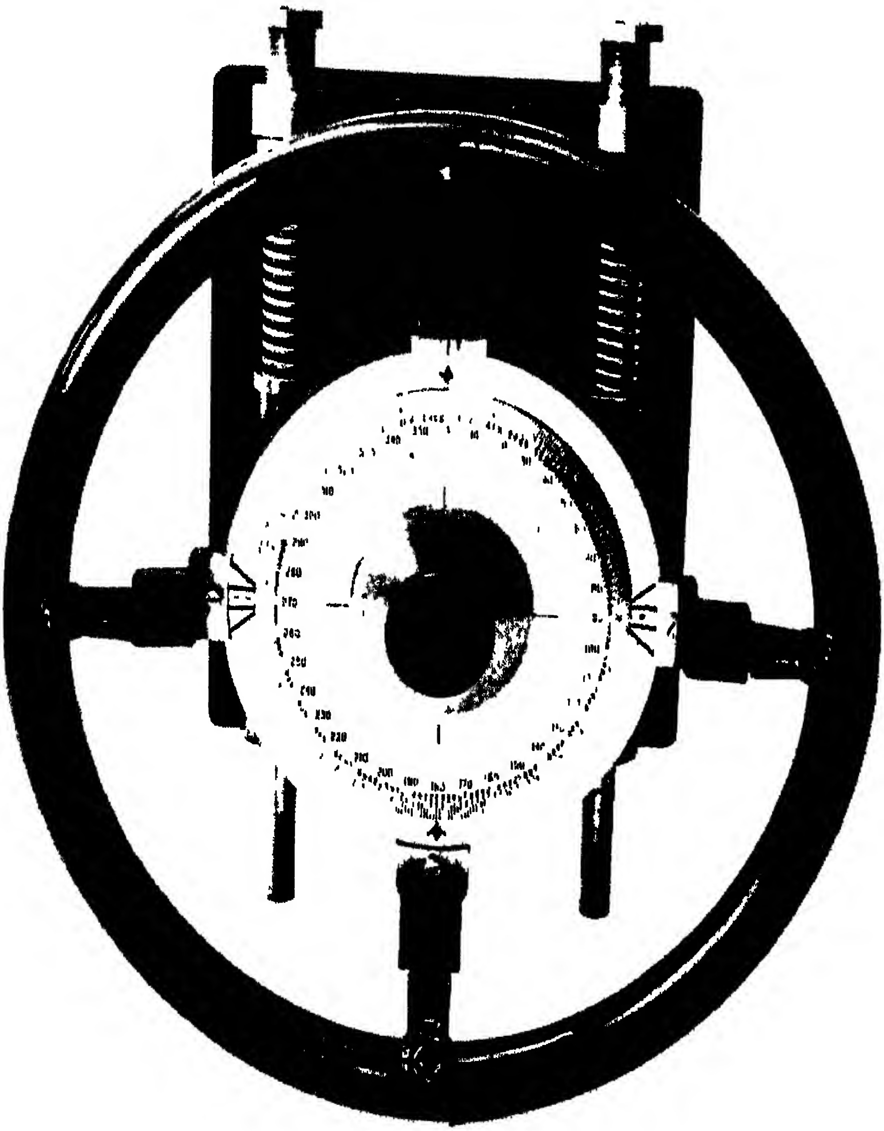

FIG. 70.—Handwheel.

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Finally, as regards item (9), it is rarely possible to instal the handwheel directly below the frame base. To allow a certain amount of flexibility in the position of the handwheel, the drive is by means of a steel cable which conveys the motion from the handwheel to the frame base. A distance of about 30 ft. between frame base and handwheel may be taken as the maximum.

Frame Windings.—These consist of fourteen turns of wire wound in two sections of seven turns each. Special precautions are taken to ensure that the inductance and capacity values of the two halves are as nearly identical as possible.

Wave-range.—The wave-range provided for ship work is from 430 to 1250 metres. This range covers all waves used in the mercantile marine for ordinary direction-finding and position-fixing work in all parts of the world. The tuning is effected by a variable condenser connected across the frame windings.

Handwheel.—This wheel (see Fig. 70) is about 16 in. in diameter, and rotates on a central ball-bearing.

Special stops are provided to absorb any shock when the frame is stopped. The amount the frame is allowed to rotate is one complete turn plus an overlap of about 30°–40°, i.e. 390°–400° altogether.

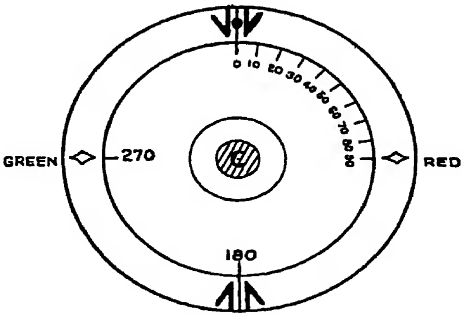


FIG. 71.

The Scale is reproduced in Fig. 71.

Every degree from 0° to 359° is marked on a fixed metal disc. The indicator ring is provided with two sets of black indicators fixed at 180° apart.

The actual calibration and the taking of bearings are done on the "spot" pointer marked V⸸V, while the other black pointer marked V|V is for checking reciprocals and the mechanical accuracy of the set.

Two additional indicators, one green and the other red, are provided at midway positions between the black indicators, and are only used for obtaining the "sense" or true direction of the bearing (see p. 47).

A clamping device C is provided to actuate two brake shoes

on the wheel drum. This enables the operator to clamp the wheel in position after use so that wind pressure on the frame will not cause it to rotate.

The frame and handwheel are coupled together by means of a stout steel cable, the middle point of which is firmly clamped to the frame base, while the two ends are solidly fixed to the handwheel. Springs with screw adjustment are provided on the frame base to permit (*a*) ease of erection, (*b*) tightening up the slack on the wire when the frame is first installed, and (*c*) expansion and contraction of the driving wire due to temperature changes.

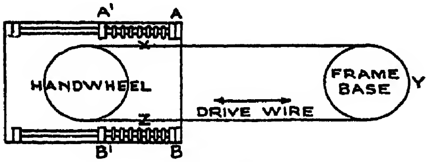


FIG. 72.

The latter is a very important point.

It is obvious that the whole calibration of the installation would be thrown out if the wires XY and YZ (see Fig. 72) expanded or contracted at different rates. To compensate for this, the wires are drawn very taut before calibration. This is accomplished by means of the adjusting screws A and B, causing the springs AA^1 and BB^1 to come under heavy pressure. Now, any expansion or contraction (which is of a very small order) of the wire cable causes the handwheel to move *as a whole* either away from the frame base or towards it. Rotary motion is entirely prevented.

Pulleys.—Small, heavily constructed pulleys are used to carry the wire between the frame base and the handwheel. All these pulleys are fitted with double ball races, which allow a very easy rotary motion, but no side play. The pulley wheels are capable of rotation through an angle of 180° about their spindles. This enables them to be set at practically any angle, thus facilitating the turning of corners with the drive wires. Fig. 73 shows the type of pulley used.

Method of Fixing the Drive-wire.—The drum of the handwheel and of the frame base respectively are identical in size, so that if one turns a complete circle, the other must also turn a complete circle. Both drums are provided with identical screw threads for carrying the wire, and are slotted in the threads for the purpose of anchoring the wire. In order to facilitate erection, the adjusting nuts on the handwheel (A and B in

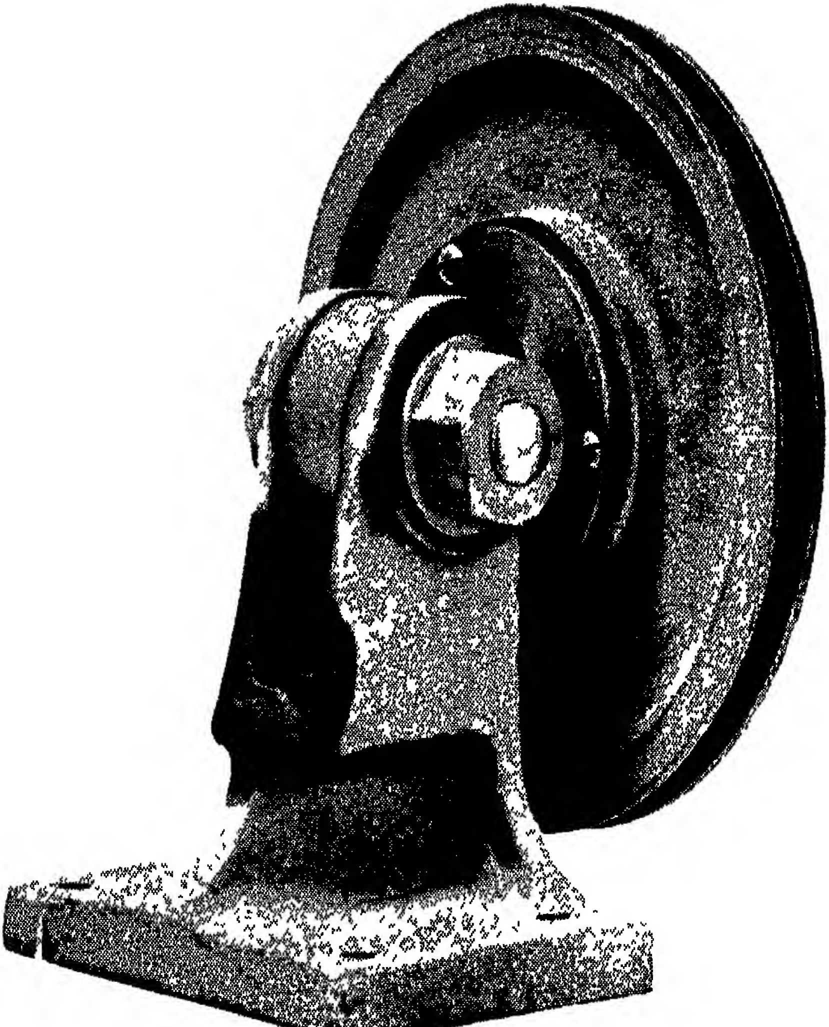


FIG. 73.—A pulley.

[*To face page* 68.

Fig. 72) should be slackened off as much as possible, and the handwheel and frame base slots arranged as shown in Fig. 74.

Then the necessary length of wire is measured off and the centre point anchored on the frame base by means of screw Y. The slots S and S_1 should be so placed as to face one another. and the handwheel clamped in position. Next, the wires are arranged as in Fig. 74 and anchored at points X and Z on the handwheel. Starting from Y, the wire makes half a turn around the drum on the frame base, half a turn around the handwheel base, and finishes at the anchorage at Z. The wire YX (shown dotted) is fixed in a similar manner, and the whole system is then tightened up by means of the adjusting screws on the handwheel (A and B in Fig. 72). The ease with which the drive works when properly installed will be understood from the fact that the frame, weighing approximately 2 cwts., can be turned by a pressure of some 2-4 lbs. on the handwheel.

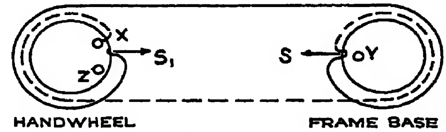


FIG. 74.

When the drive is first installed it is always advisable to make a file cut on the rotating drum of the frame base, and on the fixed metal collar surrounding it, with the spot pointer of the handwheel, say, at 0°. Then, if it is required at any time to replace the drive wire, this can easily be done by fixing the frame base and handwheel in accordance with the file marks, i.e. frame base on the file mark and the handwheel on 0°. No re-calibration will be necessary.

Receiver.—This may be divided into five distinct portions :—

(1) Amplifier.
(2) Frame tuning devices.
(3) Vertical aerial tuning devices.
(4) Coupling between frame and vertical aerial.
(5) Local oscillator.

Amplifier.—This is an instrument consisting of 7 H.F., 1 detector, and 2 L.F. valves mounted on specially sprung platforms to avoid valve microphonic noises when the ship vibrates.

The high-frequency valves are choke-coupled, the usual grid leak and grid condenser being connected between the plate of

the one valve and the grid of the succeeding valve. The L.F. valves are coupled by means of intervalve transformers.

The telephones (of the low-resistance type) are fed through a step-down telephone transformer which, by means of a switch,

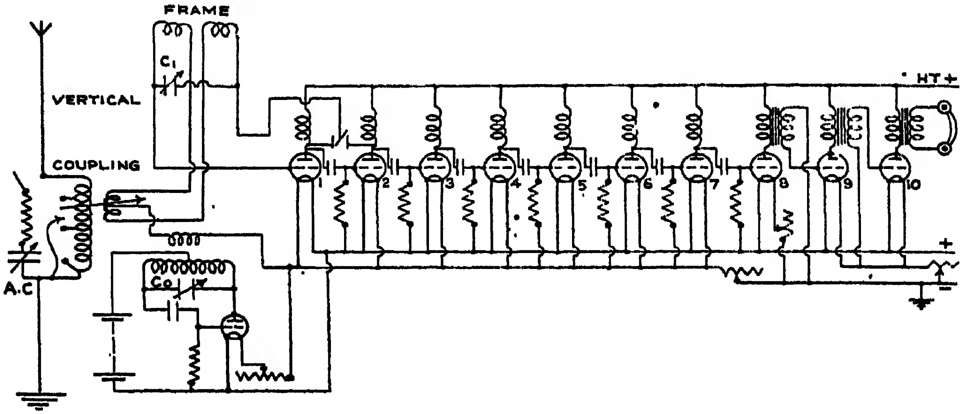


Fig. 75.

can be connected in the plate circuit of either the first L.F. or the second L.F. valve ; so that either one or two L.F. valves can be used without having to adjust the filament rheostat.

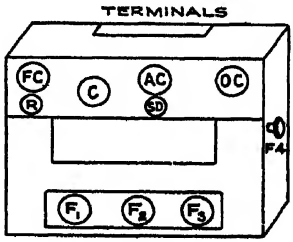


Fig. 76.

F.C. = Frame tuning condenser with vernier adjustment.
A.C. = Aerial tuning condenser with vernier adjustment.
O.C. = Oscillator tuning condenser with vernier adjustment.
R. = Reaction condenser.
S.D. = Sense-direction switch.
C. = Coupling coil between frame and vertical aerial.
F_1, F_2, F_3, F_4 = Filament rheostats.

The circuit is shown in Fig. 75, while the outside of the receiver is shown diagrammatically in Fig. 76, and photographs of the receiver are reproduced in Figs. 76A and 76B.

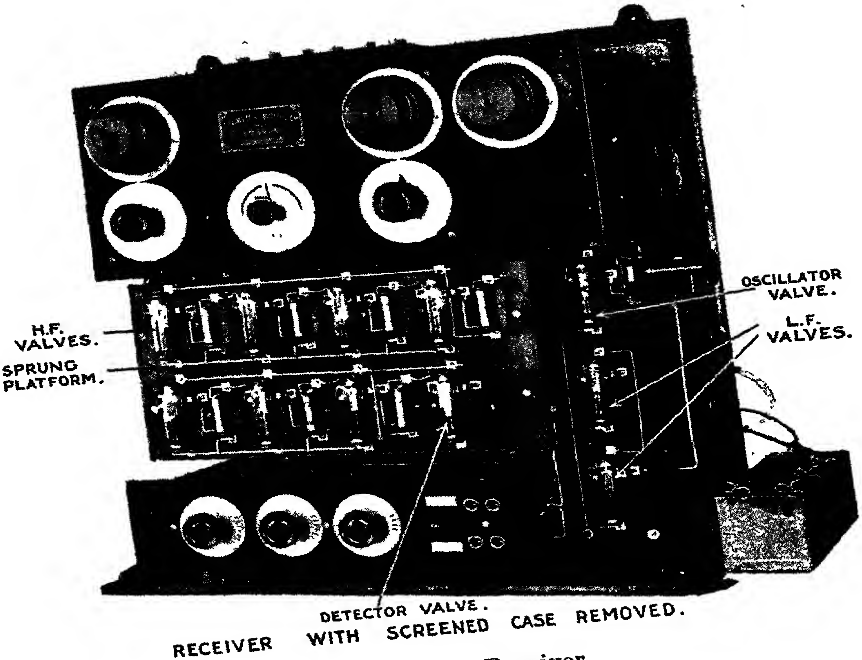
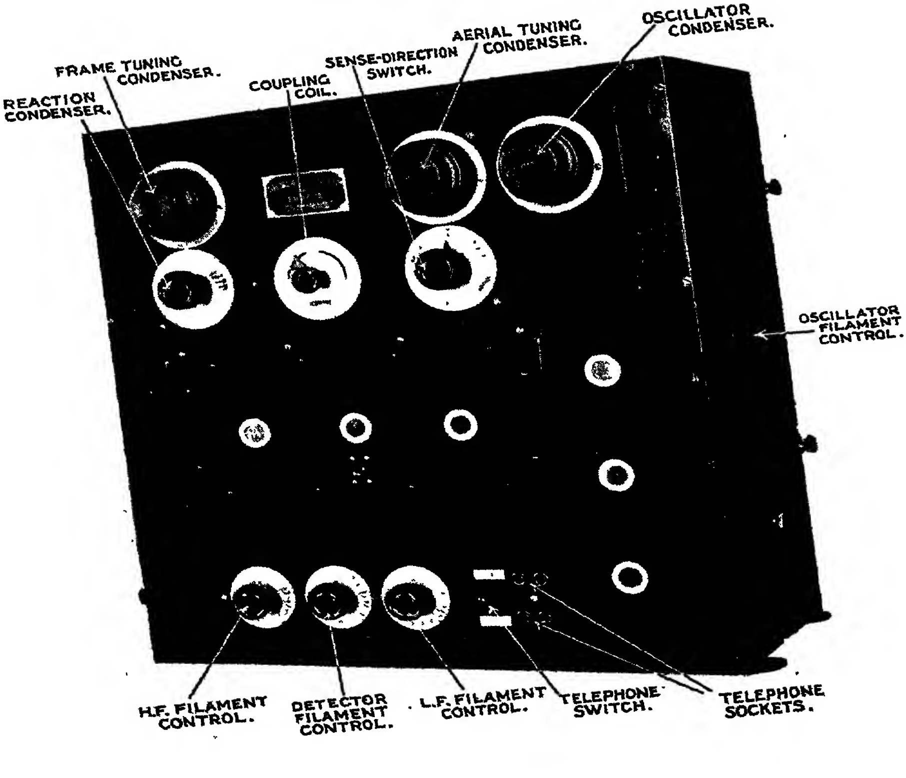


Fig. 76a.—Receiver.



Frame-tuning Devices.—These consist of a frame-tuning condenser C_1 which, when connected across the frame windings, gives a tuning range of from 430 to 1250 m.

In addition, there is a special type of *reaction condenser*, consisting of one set of movable plates and two sets of fixed plates. The movable plates are connected to one side of the frame, while one set of the fixed plates is connected to the plate of the first H.F. valve, and the other set to the plate of the second H.F. valve. In this way capacity reaction is obtained from the plate of either No. 1 or No. 2 H.F. valve on to the grid of No. 1 H.F. valve. This reaction has a very marked effect. It can be used to cut out the damping of No. 1 valve across the frame windings, thereby greatly increasing the strength of signals. In fact, its effect is equal to adding three or four extra H.F. valves to the circuit.

Capacity reaction is used in preference to inductive reaction in order to concentrate the fields, thus preventing interference with the direction of the incoming wave front, which would give a false bearing.

Vertical Aerial Tuning Devices.—These consist of two variables, firstly, an inductance with three tappings and, secondly, a variable condenser. The inductances are so chosen that, when used in conjunction with the vertical aerial, the coupling between the latter and the frame will not swing the bearings. The control of the inductances used is effected by means of the "*sense-direction*" switch. This switch has a double function. When used for direction only, i.e. with the pointer *upwards*, the vertical aerial is not tuned, but three variable tappings are available, which can be used for different wave-lengths to lengthen the aerial, and thus increase the coupling between the frame and the vertical aerial.

The object of this is to produce the equal and opposite component necessary to counterbalance the vertical effects due to the frame and direct vertical which cause flat minima (see p. 45, Fig. 54).

When used in the *sense* position, i.e. with the pointer *downwards*, this switch connects any of the three inductances across the aerial tuning condenser C_3, thus giving three separate ranges of wave-length which can be used for tuning to the wave-length of the incoming signal.

By tuning the vertical to the incoming wave-length, the requisite polar curve for a "sense" or true direction determination (as shown in Figs. 57A and 57B, p. 47) is obtained.

Coupling Coil.—This coil is connected between the vertical aerial and the frame, and is utilised to sharpen the minima when a bearing is being taken, i.e. not a "sense." It is by means of this coupling coil that the necessary equal and opposite component from the vertical aerial is taken to compensate for direct and frame vertical effects in the receiver. When "night effect" is present, the component necessary to sharpen up the minima is a variable quantity, and consequently when taking bearings during a period when "night effect" is present, it is constantly necessary to alter the position of the coupling coil. This is a valuable warning to the operator, and indicates the

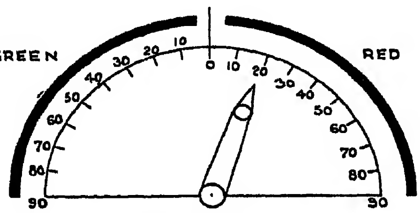


FIG. 77A.

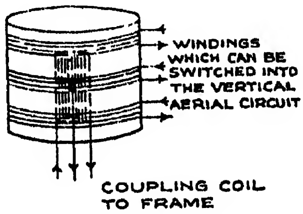


FIG. 77B.

presence of "night effect." The instructions as laid down in Chapter X. (p. 139 ff.) should be carefully followed during such periods.

The layout of this coil is shown in Figs. 77A and 77B. Fig. 77A illustrates the front of the coupling coil and Fig. 77B the arrangement inside the receiver.

The coupling coil, which is actuated by means of a spindle, can be turned through 90° either side of a central zero.

In the zero position there is no coupling between the frame and the vertical aerial, but on either the red (right) or green (left) side of the central zero there is a variable coupling up to a maximum of 90° (see Fig. 78).

It should be noted that in going through the zero position the *phase* changes 180°. If the phase on the red side, i.e. with coupling from 0° to 90°, is assumed positive, then from 0° to 90° on the green side the phase is negative. This point is very important, as it gives the necessary phase change for the deter-

mination of "sense," which is required in accordance with Figs. 57A and 57B (p. 47).

When using the D.F. set on board ship, the position of this coupling coil for sharp minima will vary according to the

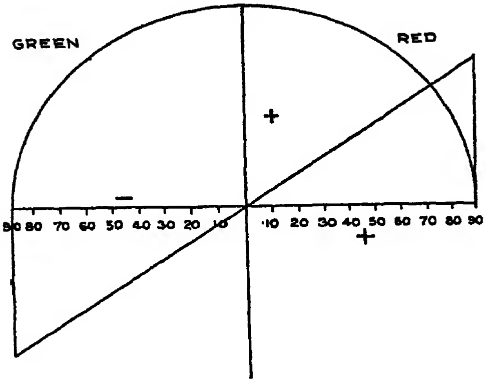


FIG. 78.

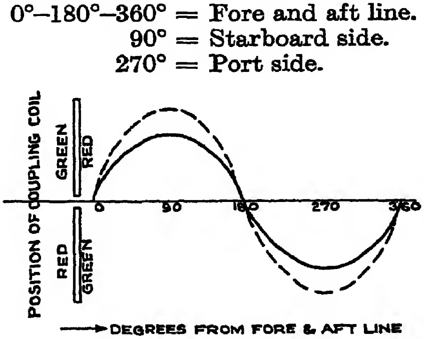


FIG. 79.

direction and wave-length of the incoming signal. This is shown in Fig. 79.

The smallest coupling between the frame and vertical will be on the fore and aft line, i.e. 0°-180°-360°, as shown in Fig. 79.

The maximum coupling will be at 90° and 270°, but in opposite senses. For shorter waves on the same ship the curve is shown dotted. In installing the vertical aerial allowance must be made for short waves.

The *characteristic* of the coupling coil for the determination of "sense" for a particular signal is shown in Fig. 80.

It will be seen that at about 20° coupling on the red scale there is a sharply defined minimum. It is the result of adding a current from the vertical aerial to that of the frame—both of which are of the same amplitude, but in exactly opposite phases—thus producing zero signals and complying with the conditions for true direction or "sense" as required by the theoretical considerations expressed in Figs. 57A and 57B (p. 47).

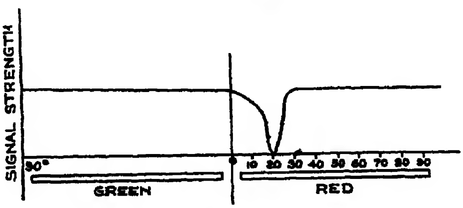


FIG. 80.

In order to comply with the other conditions, there must be :—

(1) A vertical aerial which is in tune with the incoming signals.

(2) An amplitude of signal from the vertical aerial equal to that of the frame coil.

Item (1) is fulfilled by arranging that when the "sense-direction" switch is placed on any of the downward positions, a condenser A.C. (Fig. 75) is connected across the inductance windings, thus enabling the vertical aerial to be tuned to any wave-length received on the frame.

To fulfil condition (2), the amplitude of the signal obtained on the vertical aerial is reduced to that obtained on the frame when in its zero position, i.e. to zero amplitude. This is carried out as follows, after obtaining a frame minimum :—

(1) To tune the vertical aerial, the "sense-direction" switch is put in its *downward* position on the correct wave-range. This connects condenser A.C. across the necessary inductance.

(2) The coupling coil is moved 20° or thereabouts from zero position.

(3) The vertical aerial is tuned to the incoming signal until maximum signals are heard.

(4) Keeping the vertical aerial tuned, the coupling coil is moved until signals become zero. This gives a zero amplitude of signals from the vertical, corresponding to zero signals on the frame.

(5) Keeping the coil fixed, the *pointer* is moved to zero on the coupling scale. Phases of the current from the frame and the vertical may now be added.

(6) The frame is swung from its zero position through 90°, i.e. into the position of maximum signals.

(7) The coupling coil is moved either to the left or the right until the position of minimum signal strength as shown in Fig. 80 is obtained. If this happens to be on the *red* scale on the *coupling coil dial*, the *red* pointer on *hand-wheel scale* (see Fig. 71) must be read for "sense" determination, and if the minimum comes on the *green* scale on the *coupling coil dial*, the *green* pointer must be read on the *hand-wheel scale* for "sense."

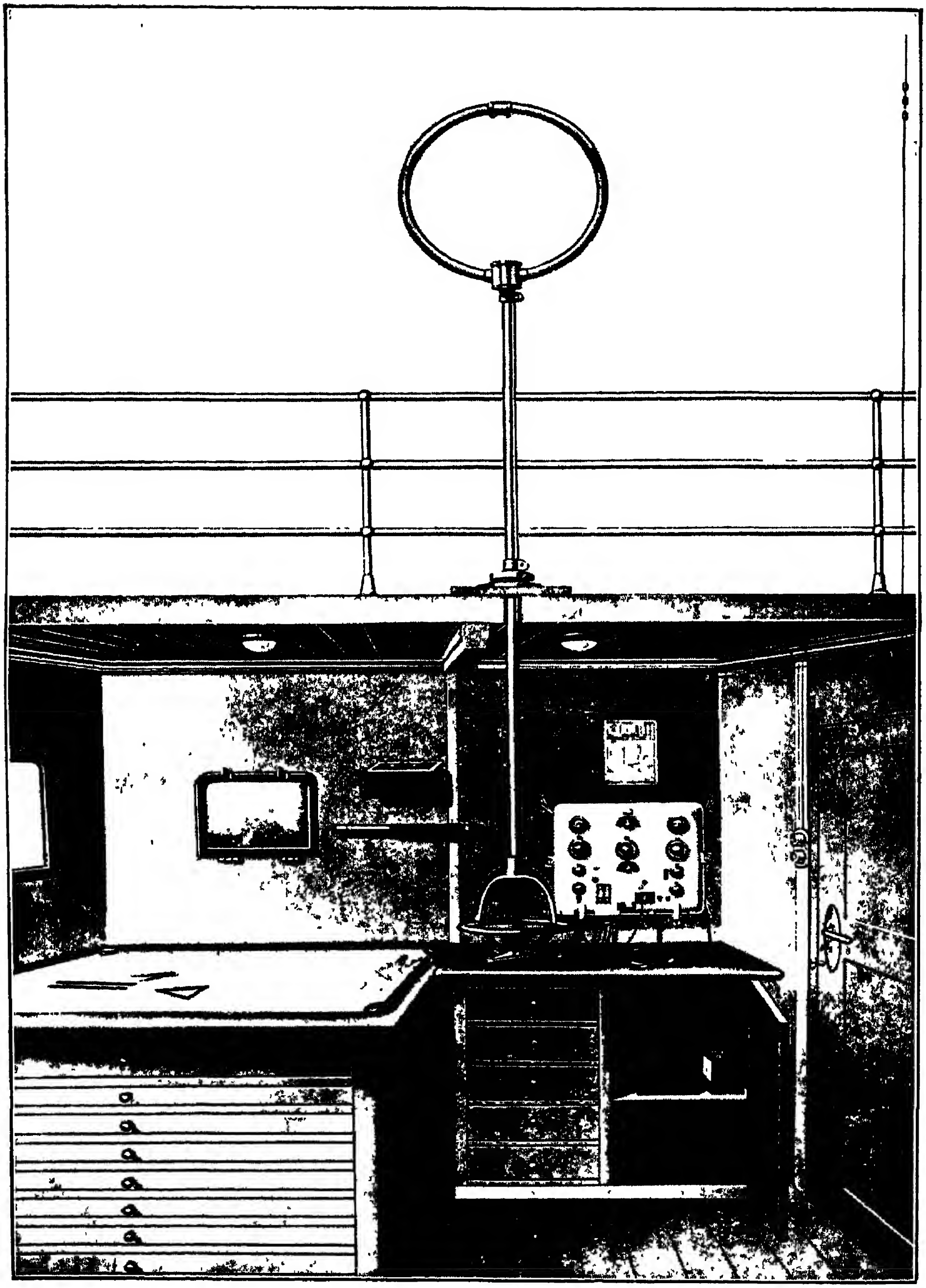


FIG. 82.—Telefunken D.F. installation.

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Local Oscillator.—This is based on the well-known Hartley circuit, and is diagrammatically shown in Fig. 81.

The variable condenser C_0 across the inductance L_0 gives a wave-range slightly greater than that covered by the frame tuning. The high tension used is usually 9-18 volts, although H.T. voltages up to 60 may be used with safety. Current for lighting the filament is obtained from the common L.T. battery for the amplifier, but there is a separate filament control on the right-hand side of the receiver (see Fig. 76).

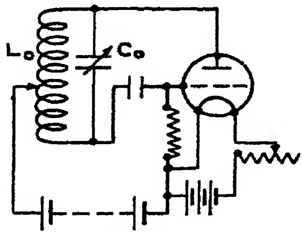


FIG. 81.

This oscillator is coupled with the earth lead of the frame, thus giving perfect symmetry. A fixed coupling coil of a few turns is used for this purpose.

It may be mentioned that when taking bearings on a C.W. station, the note of the C.W. does not in any way change in going through the minimum, as there is no possible secondary effect due to interaction of frame on frame. Moreover, the accuracy on C.W. is as great as on spark or I.C.W., the advantage of C.W. over spark being the greater selectivity.

Telefunken Apparatus.—The Telefunken Company of Berlin have in the past few years worked out a practical system of D.F. based on the single rotating frame principles with a compensating vertical aerial. The theory of compensation referred to in the last section applies to this apparatus. An illustration of the latest Telefunken apparatus is given in Fig. 82. It will be seen that the frame consists of a watertight metal ring which is directly driven by the handwheel mounted on the table. For ships where it is not possible to instal a direct drive from the frame to the handwheel, a flexible drive is employed. The circuits include four H.F. valves, one detector valve, and a three-valve resistance-coupled L.F. amplifier. A notable feature of this receiver is the fact that no separate oscillator is used for the reception of C.W. signals. This is accomplished by using the detector valve in conjunction with a tuned grid and variably coupled anode circuit, thus causing the detector valve to oscillate for C.W. reception. A variable coupling is connected between the plate of the fourth H.F.

valve and the tuned grid of the detector valve. The following advantages are claimed for a receiver of this type :—

(1) A high degree of selectivity due to the tuned detector valve grid.

(2) No additional oscillator valve is necessary for the reception of C.W. signals.

Fig. 82 shows the complete D.F. installation with high and low tension batteries. The compensating vertical aerial is shown on the extreme right.

It is of interest to note that the location of the sinking S.S. "Laristan," which came prominently before the public early in 1926, was effected by means of the Telefunken apparatus installed on the North German Lloyd steamer "Bremen."

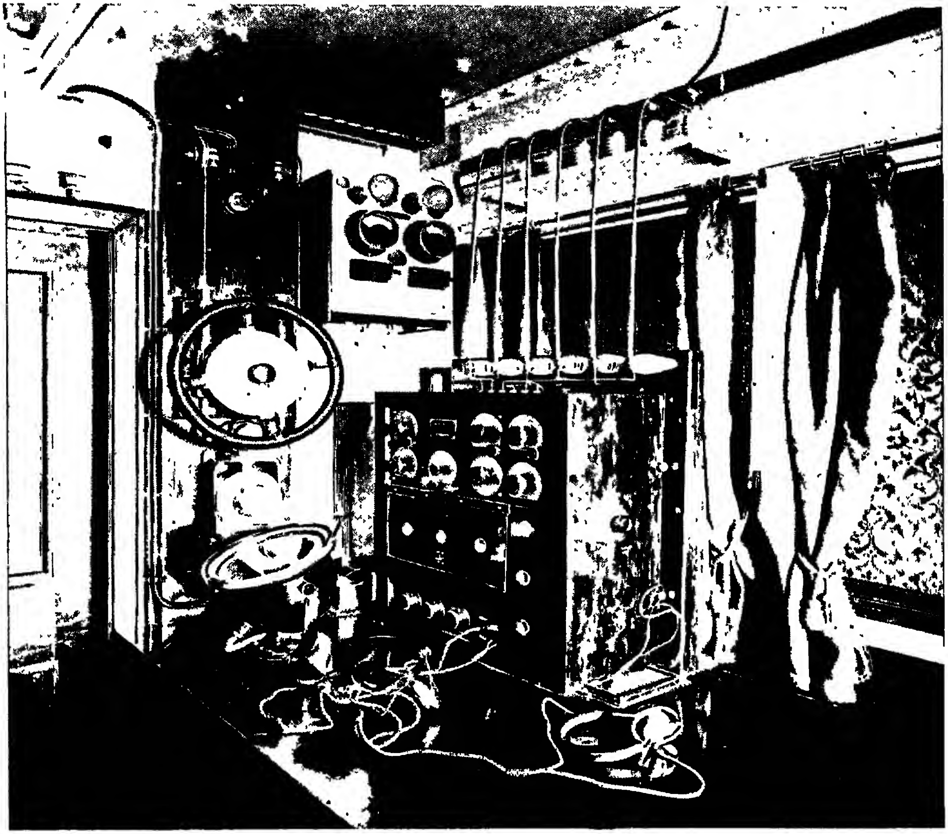


FIG. 83.—D.F. receiver in chartroom of M.S. "Gripsholm."

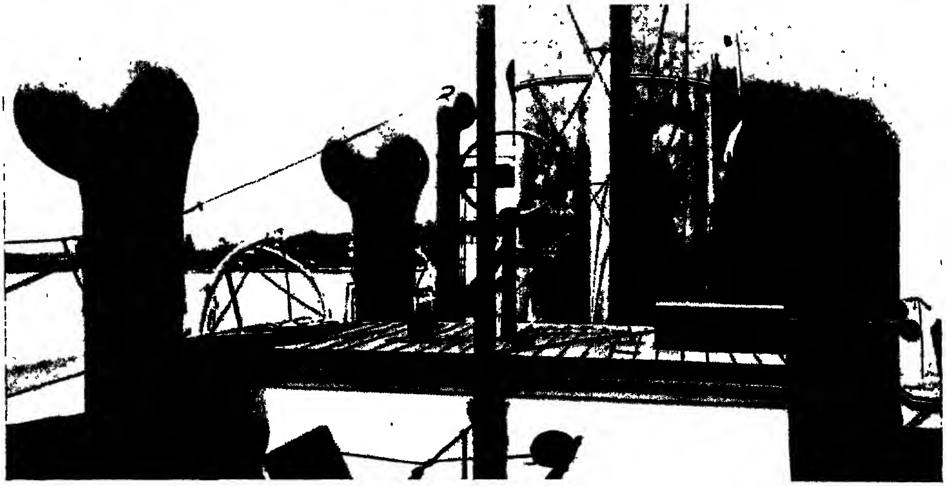


FIG. 84.—D.F. frame on wireless cabin, S.S. "Port Macquarie."

[*To face page* 77.

CHAPTER V.

INSTALLATION OF A SINGLE-FRAME AERIAL ON A SHIP.

Position on the Ship.—The success of an installation is largely dependent on the method of installation.

There are two obvious possible positions for the frame :—

(*a*) On the bridge (see frontispiece, which shows the frame on the bridge of T.M.S. " Gripsholm " ; also Fig. 83).

(*b*) On the roof of the W/T cabin (see Fig. 84), which shows the frame on the W/T cabin on the S.S. " Port Macquarie ".

Advantages of Installing the D.F. Set on the Bridge.—Purely from a D.F. point of view, position (*a*) is undoubtedly the best, as it gives a clear field of view on the bows, i.e. in Nos. 1 and 4 quadrants. This means that when the Quadrantal Error Curve is taken (see Chapter VI.), the deviations from the true straight line curve will be small, and the consequent liability to error will also be small. Also, all electrical instruments and lighting cables, etc., going to the bridge are well screened and earthed so as to prevent electrical influences on the magnetic compass. This screening is a distinct advantage, as it minimises any induction into the D.F. receiver.

The *disadvantages* of having the D.F. set on the bridge are :—

(1) If worked by W/T operators, it is by no means a convenient place, as it is very unsatisfactory to have to go from the W/T cabin to the D.F. set on the bridge in order to take a bearing.

(2) Additional controls are required to operate from the W/T cabin to the bridge.

In some countries—especially in America and Germany—the D.F. set is looked upon purely as a navigating instrument, and it is actually worked and maintained by the navigating

officers. This is a great advantage, provided that the navigating officers are properly trained in the working and maintenance of the set. This, unfortunately, is not always the case, and the work then falls on the W/T operator.

With regard to (2), the additional controls are minor details which can be easily overcome. A little extra expense, however, is entailed in running cables from the D.F. set to the bridge to operate the telephone and the relay.

With respect to alternative (*b*), i.e. where the frame is mounted on the roof of the W/T cabin, this has the following *disadvantages* :—

(1) Generally, this position is screened by metal masses, such as funnels, etc., and consequently the Quadrantal Error Curve gives bigger deflections than if the frame were installed on the bridge. Hence there is a greater liability to error.

(2) Lack of good liaison between the W/T and navigating personnel.

On the other hand, this position has the following great *advantages* :—

(*a*) The set is operated by skilled personnel who can take bearings not only on fixed beacon stations, but on all ships, etc. This is especially useful in fog.

(*b*) There is no time lost in the W/T operators going between the W/T cabin and the bridge to take bearings.

(*c*) The D.F. receiver can also be used for duplex work.

Choice of Site : General Considerations.—

(1) This should provide as clear a field of view as possible.

(2) It should be such that the frame is as near as possible on the fore and aft line of the ship.

(3) It should be so chosen that the bottom of the frame loop is, if possible, above near metal structures such as railings, ventilators, stays, etc. (see Chapter VI.).

(4) It should be in such a position as to entail the shortest possible length of driving wire between the frame base and the handwheel and receiver.

(5) It should be as far as possible away from any motors, such as ventilator motors, etc.

(6) It should be away from, or above, any closed earthed loops (see Chapter VI.).

(7) It should be away from passenger decks, if possible.

(8) If it is necessary to choose a place surrounded by ventilators, then the loop should be placed as nearly symmetrical to the ventilators as possible.

Vertical Aerial.—This plays a very important part in the success of the installation. It must be remembered that this vertical aerial supplies an E.M.F. of an equal and opposite phase to that in the frame, to counterbalance the false vertical which is an inherent part of the D.F. installation (*vide* Fig. 51, p. 43); and is due to—

(*a*) Direct vertical effect of the receiver.

(*b*) Vertical effect due to the frame acting as a vertical aerial.

No definite length can be assigned to this vertical aerial. Experience shows that it depends on the size and nature of the

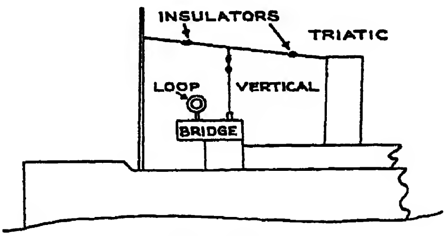


FIG. 85.

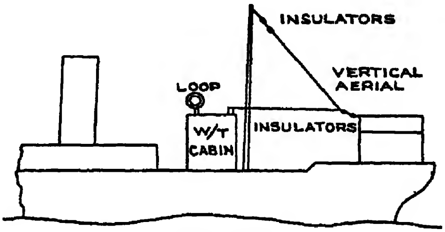


FIG. 86.

ship and the distribution of the metal masses on the ship relative to the position of the rotating frame. The lengths may vary between 15 ft. on some ships up to 30 ft. on others.

The best method of arranging this vertical aerial is indicated in Fig. 85.

It will be seen that this is done by running a triatic between the forward mast and the funnel and insulating it as shown. The vertical aerial is then attached to the triatic by means of insulators.

In cases where a triatic is not feasible, the method illustrated in Fig. 86 may be used with advantage.

It will be seen that a small mast about 20 ft. high is used, the length of the required vertical being adjusted on the "tie-back" until the aerial length is of the correct value.

If this vertical aerial is too short, then obviously—

(*a*) Even with maximum coupling between the vertical aerial and the loop, i.e. with the "sense-direction" pointer to the maximum coupling position and the coupling coil at the 90° position, there will be insufficient coupling to counteract the "vertical" effect in the receiver.

(*b*) The requisite wave-range for tuning for "sense" determination will not be achieved.

If the vertical aerial is too long, then—

(1) Even with weak coupling between the loop aerial and the vertical aerial, the amount of energy passing from the vertical aerial into the loop will be so great that the direction of the incoming wave will only be apparent, and a false bearing will be the result.

(2) The tuning on "sense" will be such that the ranges on the "sense-direction" will be too great.

A rough rule is that the length of the vertical aerial should be such that its natural period in conjunction with the lengthening coil lies 20 per cent. in wave-length below the minimum range of the scale.

Position of sense-direction switch.	Wave range.	Natural wave-length of vertical + lengthening coil.
	m.	m.
1	400- 600	320
2	600- 900	480
3	900-1400	720

Attention should be paid to the following points: On the low wave-lengths, i.e. about 450-550 m., the vertical aerial on the third range (i.e. 900-1400 m.) is nearing resonance with the incoming wave-length, and consequently will be much more active and liable to swing bearings on these wave-lengths. In installing, allowance must be made for this by selecting an appropriate aerial length.

Care must also be taken to keep the horizontal distance from the bottom of the loop to the vertical aerial at least about 6 ft., and this distance must not be less at higher points of the loop aerial.

Wiring from the Loop to the Receiver.—The wiring—which should be of specially heavy copper wire, nickel-plated—is shown in Fig. 87, and serves the following requirements :—

(*a*) To minimise capacity effects and facilitate tuning.

(*b*) To prevent leakages of energy to earth and ensure that bearings are not swung due to these leakages.

The whole wiring is screened in order to minimise direct action into the receiver, and to cut down any "vertical" effect.

Attention is drawn to the fact that a central "earth" is run from the frame down to the receiver. This is to keep perfect symmetry throughout the whole installation.

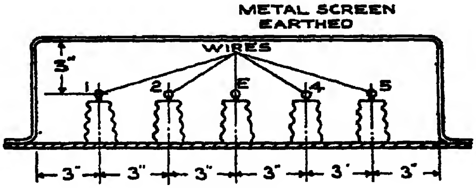


FIG. 87.

In cases where the distance from the frame base to the receiver is short, say, 10-12 ft., the distance between the wires may be reduced to 2 in.

Fixing the Handwheel.—This must be done with regard to the conditions on the ship, the two points to be observed being :—

(1) To make the drive as short as possible.

(2) To make quite sure that when the drive rotates from 0° to 90° the frame turns *clockwise*.

A good nethod of arranging the handwheel is shown in the photograph of T.M.S. "Gripsholm" (Fig. 83). It will be seen that the Gyro repeater dial is mounted near the handwheel, so that the operator can read simultaneously :—

(1) W/T bearing on the handwheel, and

(2) Ship's head relative to true north.

(See Chapter VIII.)

The telephone communicating to the W/T room is seen beneath the handwheel.

In ships without a gyro-repeater, a bell push is arranged beneath the handwheel for communication with the standard compass platform. When the operator takes a bearing, he presses the bell and a reading is made on the standard compass simultaneously.

Low-tension Wiring.—This runs from the batteries to the charging board and to the receiver, and should be of heavy gauge lead-covered wire. The lead casing as well as the L.T. negative of the battery should be earthed.

Low-tension Batteries.—These consist of two 6-volt accumulators and arrangements are made on the charging board that one battery is being charged while the other is in use.

Instructions regarding battery maintenance are issued with each installation, and these should be carefully adhered to in order to obtain the maximum efficiency from the receiver. If the batteries are allowed to run down, it would result in :—

(*a*) Diminished signal strength.
(*b*) Crackling noises in the amplifier.

The instructions regarding battery maintenance, referred to above, are reprinted in Appendix I.

Auxiliary Controls in Connection with D.F. Sets.—The two cases to be considered are :—

(1) Where the D.F. set is in the W/T cabin and worked by the W/T operator (see Fig. 88).
(2) Where the D.F. set is on the bridge, and is operated either by the W/T operator or the navigating officer (Fig. 89).

In case (1), i.e. when the D.F. set is in the W/T cabin, arrangements must be made to—

(*a*) Isolate the main aerial when taking bearings.
(*b*) Protect the D.F. receiver in such a way that any transmission from the main set will not damage the receiver.
(*c*) Have telephonic communication between the chart-room and the W/T room.
(*d*) Have a warning system from the W/T room to the navigating officer who observes the visual bearing for calibrating and checking the Q.E. curve, and who also reads the ship's head at the time bearings are taken.

Regarding item (*a*), the main aerial must be isolated to prevent its influencing the direction of bearings on incoming signals. This is done by a switch which lights a lamp over the D.F. set when the main aerial is broken. The burning of this lamp warns the D.F. operator that it is safe to take a bearing.

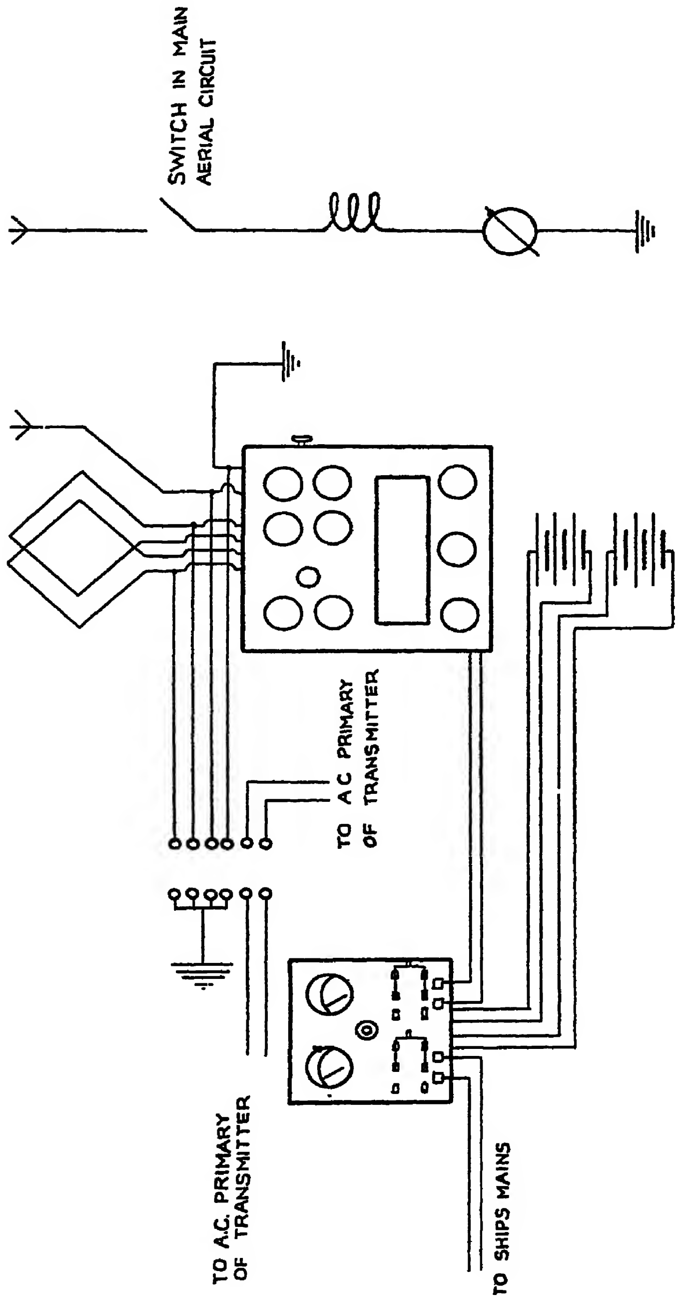

SWITCH IN MAIN
AERIAL CIRCUIT
TO A C PRIMARY
OF TRANSMITTER
TO A.C. PRIMARY
OF TRANSMITTER
TO SHIPS MAINS

FIG. 88.

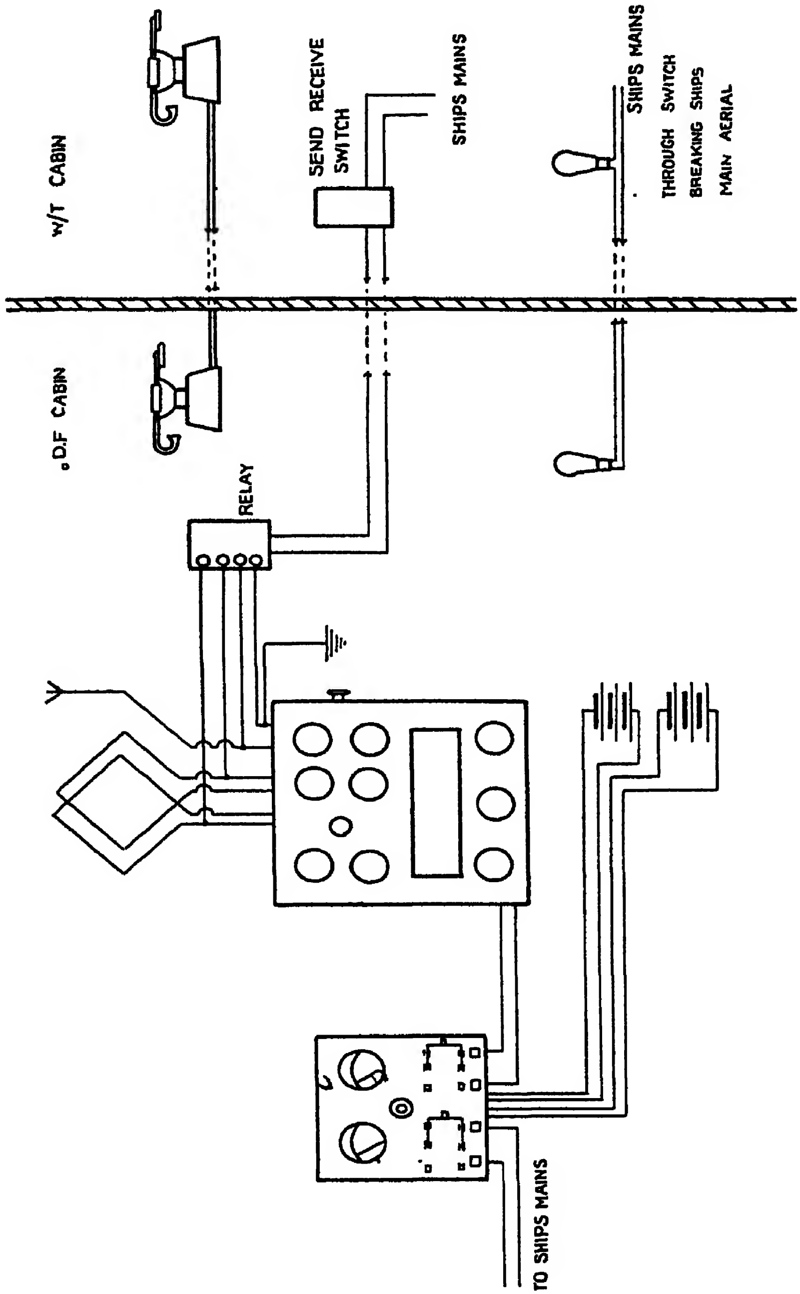
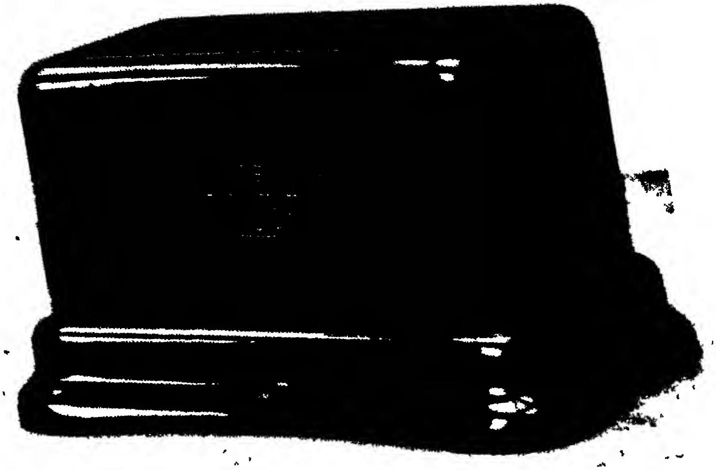

W/T CABIN
D.F CABIN
SEND RECEIVE SWITCH
SHIPS MAINS
SHIPS MAINS
THROUGH SWITCH BREAKING SHIPS MAIN AERIAL
RELAY
TO SHIPS MAINS

FIG. 89.



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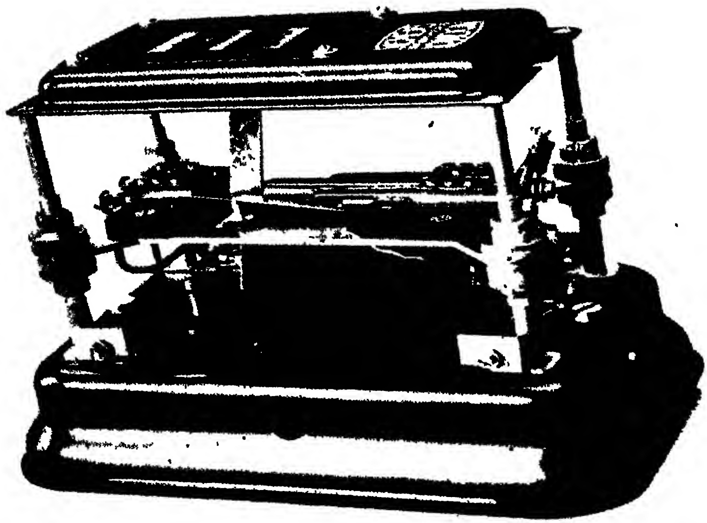


With cover removed.

FIG. 90.—Relay.

[To face page 85.

Regarding (*b*), this is done by shorting the outer windings of the loop and the vertical aerial to earth, and by breaking the main transmitter primary when the D.F. receiver is not earthed. A hand-switch or relay may be used for this purpose.

Concerning (*c*), this is essential for the purpose of transmitting bearings from the W/T room to the chart-room.

As regards (*d*), this is necessary for checking the calibration curve on visual observations, the latter being taken by the navigating officer on the standard compass platform. In cases where the ship's head is observed by the navigating officer, i.e. in ships where there is no gyro repeater dial in the W/T cabin, the same warning system can be used to signal the navigating officer to read the ship's head from the standard compass when the W/T bearing is taken.

The warning system used generally consists of a watertight single-stroke gong to avoid confusion with other bell systems usually to be found on the bridge of modern liners.

In case (2), i.e. with the D.F. set on the bridge, arrangements must be made to—

(*a*) Isolate the main aerial when taking bearings.

(*b*) Protect the D.F. receiver, and break the main transmitter circuits.

(*c*) Have telephonic communication between the D.F. set and the chart-room (usually the D.F. set is placed in the chart-room on the bridge).

(*d*) Have telephonic communication between the D.F. set to the point of visual observation.

(*e*) Have a warning system from the D.F. set to the point of visual observation.

The same remarks apply to items (*a*), (*c*), (*d*), and (*e*) as in the previous case discussed above.

Regarding item (*b*), in this case a relay is employed.

Relay.—The relay (Fig. 90) is designed to work directly on the ship's mains, i.e. either on 110 or 220 volts, depending on the ship's working pressure.

When the main transmitter is working, the relay is energised, and the contacts 1, 5, A, and E are all connected to the main earth (E). When the "send-receive" switch is placed in the "receive" position, then the relay is not energised

and the contacts 1 and 5 and A and E are disconnected from the main earth (E). In this position the D.F. receiver can be used to take approximate bearings on incoming signals. A proper bearing, however, should not be taken until the *main aerial is broken.* The breaking of the main aerial is shown by the lighting of the warning lamps both in the W/T cabin and near the D.F. receiver.

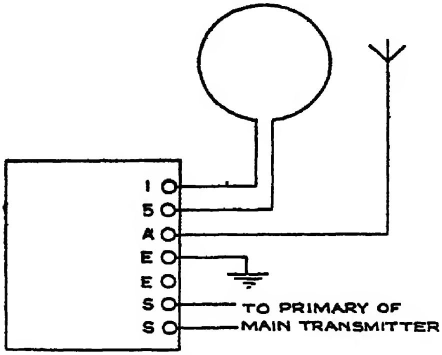


FIG. 91.

A bearing should never be taken unless the warning lamps are lighted, i.e. unless the main aerial is broken.

INSTRUCTIONS FOR OPERATING THE SIEMENS DIRECTION FINDER.

Usually "direction" alone is required, and only rarely "sense" or true direction.

Each receiver should be calibrated and curves drawn showing the adjustments on all wave-lengths of—

(*a*) Frame condenser.
(*b*) Vertical aerial condenser.
(*c*) Local oscillator condenser.

The wave-length of the transmitting station is usually known, and the condensers should be adjusted to correspond to these wave-lengths by reference to the curves.

"Direction" on Spark or I.C.W. Signals.—

(1) See that the coupling pointer is in the centre of the scale. If this is so, a rotation of 90° on either side will cause the pointer to cover the whole scale.

(2) Adjust for maximum signals by using the frame condenser and the reaction condenser.

(3) Rotate the handwheel until the position of the approximate minimum is found.

(4) With the "sense-direction" pointer upwards, and on the correct wave-range, adjust the coupling coil and the hand-

wheel simultaneously for a dead sharp minimum, and read the bearing given on the handwheel by the "spot" pointer marked V♦V. This is the direction of the incoming wave.

Should it be impossible to obtain a point bearing, i.e. one to within 1°, then swing the frame about the zero position. Match the bearings on either side of this minimum and take a mean; for instance, if the signals are of equal strength at 35° and 41°, the bearing is $\frac{35 + 41}{2} = 38°$.

"Sense" or True Direction on Spark or I.C.W. Signals.—

(1) See that the coupling pointer is central.

(2) Adjust for maximum signals by using the frame condenser and the reaction condenser.

(3) Rotate the handwheel for approximate zero.

(4) With the "sense-direction" pointer upwards and on the correct wave-range, adjust the coupling coil and the handwheel simultaneously for a sharp zero.

(5) Leaving the frame at zero, move the "sense-direction" switch downwards to the correct wave-range.

(6) Move the coupling coil 20° or more to the right or left.

(7) Tune the vertical aerial by means of the vertical aerial tuning condenser for maximum signals.

(8) Move the coupling coil until signals are zero.

(9) Keeping the coupling coil fixed, move the coupling coil pointer to the centre position.

(10) Swing the frame through 90°, i.e. into the position of maximum signals.

(11) Rotate the coupling coil to the right or left, noting the colour (red or green on dial) on which signals weaken.

(12) Read "sense" or true bearing on the pointer that has the same colour as the coupling dial which indicates weak signals, e.g. if in (11) weak signals come in on the red side of the coupling dial, then read the red pointer on the handwheel for "sense."

"Direction" on C.W. Signals.—

(1) See that the coupling pointer is central.

(2) Adjust for maximum signals on the frame condenser, reaction condenser, and oscillator condenser (the oscillator being switched on by the oscillator filament switch).

(3) Rotate the handwheel until the position of approximate minimum is found.

(4) With "sense-direction" pointer upwards and on the correct wave-range, adjust the coupling coil and the handwheel simultaneously for a dead sharp minimum, and read the bearing given on the handwheel.

"Sense" or True Direction on C.W. Signals.—

(1) See that the coupling pointer is central.

(2) Adjust for maximum signals, using the frame condenser, reaction condenser, and local oscillator.

(3) Rotate the handwheel to the position of approximate zero.

(4) With the "sense-direction" pointer upwards and on the correct wave-range, adjust the coupling coil and the handwheel simultaneously for a sharp zero.

(5) Leaving the frame at zero, move the "sense-direction" switch downwards to correct wave-range.

(6) Move coupling coil 20° or more to the right or left.

(7) Tune the vertical aerial by means of the vertical aerial tuning condenser for maximum signals.

(8) Move the coupling coil until the signals are zero.

(9) While keeping the coupling coil fixed, move the coupling coil pointer to the centre position.

(10) Swing the frame through 90°, i.e. into position of maximum signals.

(11) Rotate the coupling coil to the right or left, noting the colour (red or green on dial) on which signals weaken.

(12) Read "sense" or true bearing on the pointer that has the same colour as the coupling dial which indicates weak signals, e.g. if in (11) weak signals come in on the green side of the coupling indicator dial, then read the green pointer on the handwheel for "sense."

Faults and Their Elimination.—The following table will be of use in handling the set :—

Fault.	Cause.	To rectify fault—
A. On Switching on.		
1. All valves do not light up.	Batteries not switched on.	Switch on battery.
	Battery L.T. circuit broken.	Examine and rectify fault in L.T. battery circuit.
2. One valve does not light.	Valve faulty or valve contact faulty.	Change valve to another position in amplifier. If it does not light up, replace it. If it lights up, repair valve contacts in old valve position.
3. Valves burn dimly.	L.T. batteries not fully charged.	Check voltage with voltmeter and, if below 1·8 per cell, recharge battery. In the meanwhile use other L.T. battery.
B. Reception of Spark Stations.		
1. Reaction condenser does not give a "click" in the phones on being swung through 180°.	(*a*) Low-tension battery low.	(*a*) Same as (3).
	(*b*) H.T. battery not plugged in.	(*b*) Plug in H.T. plugs with negative at 0, Rect. at 18-24, H.T. at 30-48, L.F. 42-66 volts.
	(*c*) Insufficient H.T.	(*c*) Test H.T. battery with voltmeter and, if not giving desired voltage, replace battery by spare.
	(*d*) Frame leads broken.	(*d*) Test (1) to (2) on frame and (4) to (5) on frame with galvanometer. If broken, repair.
	(*e*) Lead broken on reaction condenser.	(*e*) Reaction condenser lies between (1) and (5) on frame and should be tested for continuity, and repaired if broken.
	(*f*) Frame damp inside.	(*f*) This fault is exceptional. If the frame can be dried in sunlight, this should be done. A blow-lamp can also be used with care to dry out the frame.
	(*g*) Bad valve.	(*g*) Test all valves by shorting from grid of the detector valve to plates of 7, 6, 5, 4, 3, 2 valves respectively. On each plate the reaction con-

Fault.	Cause.	To rectify fault—
		denser should give a click on turning through 180°. If not, replace valve immediately preceding connecting wire.
2. No signals can be heard.	(*a*) H.T. battery not switched in.	(*a*) Plug in H.T. plugs. Test by putting switch on to "1 valve"-"2 valve" position. If H.T. is on, then clicks will be heard in the telephone.
	(*b*) Reaction is at zero. This causes heavy damping across frame and renders amplifier insensitive to weak signals.	(*b*) Turn reaction condenser to more sensitive position.
	(*c*) Relay is shorting frame and vertical to earth.	(*c*) Examine relay and adjust to work correctly.
	(*d*) Main transmitter is at "Transmit."	(*d*) Put over to "Receive."
	(*e*) Frame is on minimum.	(*e*) Turn handwheel through 90°.
	(*f*) Frame not tuned.	(*f*) Tune frame by frame condenser.
	(*g*) Station not sending.	(*g*) Confirm by listening-in on main receiver, or by giving the station a call on main transmitter.
3. Signals weak, but note is characteristic.	(*a*) L.T. or H.T. batteries run down.	(*a*) See A3 and B (*c*).
	(*b*) Frame not tuned.	(*b*) Tune frame.
	(*c*) Reaction requires adjusting.	(*c*) Adjust reaction condenser 20°-30°.
4. Signals weak, and note is not characteristic.	(*a*) Reaction condenser over-coupled.	(*a*) Move reaction condenser 20°-30° towards 0°.
C. Reception of C.W. Signals.		
(1), (2), (3), (4) as for spark signals.	As for spark signals.	As for spark signals.
5. No signals.	Oscillator not working due to—	
	(*a*) Bad valve.	(*a*) Replace valve.
	(*b*) H.T. not plugged in.	(*b*) Plug-in H.T. (9 volts upwards suitable).

Fault.	Cause.	To rectify fault—
	(c) Valve not switched on.	(c) Switch on valve. To test if oscillator is working, put reaction condenser to 180° and rotate oscillator condenser. This gives numerous C.W. oscillations in phones.
6. Weak signals.	(a) Oscillator is badly tuned.	(a) Tune oscillator.
	(b) Oscillator is over-coupled.	(b) Reduce H.T. or adjust filament rheostat of oscillator valve to dim valve.
7. Howl in telephones which changes as oscillator condenser is moved.	(a) Amplifier oscillating due to reaction being too strong.	(a) Move reaction condenser 20°-30° towards 0° position.
D. Bearings.		
1. Wide minima.	(a) Distance of transmitter too great.	(a) Take swing bearings.
	(b) Receiver not sufficiently sensitive.	(b) Adjust tuning and reaction for maximum signals.
2. Blunt minima.	(a) Frame not on minimum, and coupling between frame and vertical aerial not properly adjusted.	(a) Adjust coupling handle and handwheel simultaneously to get sharp minimum.
	(b) Main aerial not isolated.	(b) Isolate main aerial.
3. Minima wandering.	(a) Ship rapidly changing course.	(a) Avoid taking bearings if possible during this period.
	(b) Night effect present.	(b) Take a number of bearings on the transmitter over a period of, say, 2 or 3 minutes and take a mean.
4. Bearings very inaccurate.	(a) Metal masses near D.F. frame have been altered since the calibration was done.	(a) Either get back to original metal distribution or recalibrate.
E. "Sense."		
No sharp definition.	(a) Generally due to vertical aerial not being accurately tuned.	(a) Move coupling coil and vertical tuning condenser simultaneously. Tuning condenser should be moved about the approximate tuning position.

Fault.	Cause.	To rectify fault—
	(*b*) Frame not exactly 90° to minimum. This may be due to bad operating or ship altering course during observation.	(*b*) Care should be taken to swing frame 90° from minimum position, and ship should be held on course while observation is made.
Doubt as to colour to choose in "sense" determination.	(*a*) Before the frame was tuned to maximum position, the pointer had not been adjusted to zero.	(*a*) Repeat observation, taking care to bring vertical aerial to zero position by adjusting the coupling coil and then move the coupling pointer, retaining the coupling coil fixed, before swinging the frame through 90°.

CHAPTER VI.

THE DEFLECTION OF WIRELESS BEARINGS DUE TO THE SHIPS METAL MASS

In the normal course of events, wireless waves travel across the earth in great circles. If one considers the effect of the ship's metal mass, i.e. ship's hull, antennæ, masts, etc., one finds that the waves are all deflected towards the fore and aft line of the ship.

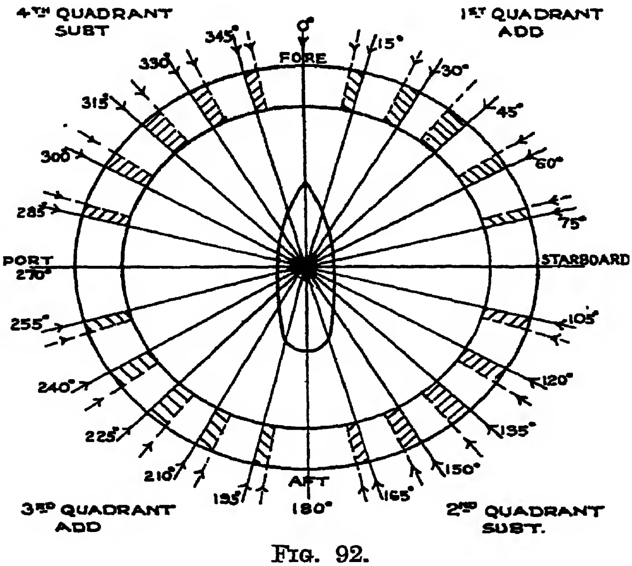


FIG. 92.

In Fig. 92 the full line represents the true direction of the transmitting station, as observed visually, while the dotted line represents the direction of the wireless bearing on the transmitting station.

It is seen that the following occurs when reading the bearings on a 360° compass with the ship's head as 0° :—

(1) All W/T bearings in the first quadrant, i.e. from 0° to 90°, or from dead ahead to starboard beam, are too small, and consequently a correction must be *added to the wireless bearing* to get the *true bearing* relative to the ship's fore and aft line.

(2) All W/T bearings in the second quadrant, i.e. from 90° to 180°, or from starboard beam to dead astern, are too large, and consequently a correction must be *subtracted from the wireless bearing* to get the true bearing relative to the ship's fore and aft line.

(3) All W/T bearings in the third quadrant, i.e. from 180° to 270°, or from dead astern to port beam, are too small and consequently a correction must be *added to the wireless bearing* to get the true bearing relative to the ship's fore and aft line.

(4) All W/T bearings in the fourth quadrant, i.e. from 270° to 360°, or from port beam to dead ahead, are too large, and consequently a correction must be *subtracted from the wireless bearing* to get the true bearing relative to the ship's fore and aft line.

(5) W/T bearings on the fore and aft line, and on the athwartships line, are not deflected.

The above represents an ideal case in which the direction-finder frame is situated on the fore and aft line of the ship, and all bearings are taken on a 360° compass, and are relative to the fore and aft line of the ship. Later on, the influence of the movement of the frame off the fore and aft line on the deflection of the W/T bearings will be examined.

It should be noted that the deflection of the wireless bearings due to the distribution of the metal of the ship is very similar to the deviation produced on the magnetic compass due to the distribution of the ship's metal masses. Just as a ship's magnetic compass must be adjusted, and a deviation curve obtained, so must a correction curve be obtained for the deflection of the wireless waves. This correction curve is called the *Quadrantal Error Calibration* curve, or Q.E. of the set.

This W/T correction curve can approximately be represented by a sine curve. In Fig. 93 the W/T bearings are shown as abscissæ and the quadrantal corrections as ordinates. The maximum corrections shown are 15°.

From this curve it is apparent that the maximum corrections occur at 45°-135°-225°-315°.

Let α = W/T angle read on W/T 360° compass.
β = correction factor.
Then β varies as $\sin 2\alpha$.

Sin 2α reaches maximum positive value at $2 \times 45° = 90° = +1$.
" " " negative " " $2 \times 135° = 270° = -1$.
" " " positive " " $2 \times 225° = 450° = 90° = +1$.
" " " negative " " $2 \times 315° = 630° = 270° = -1$.
For $\alpha = 0°$; 90°; 180°; 270°. $\sin 2\alpha = 0 = \beta$.

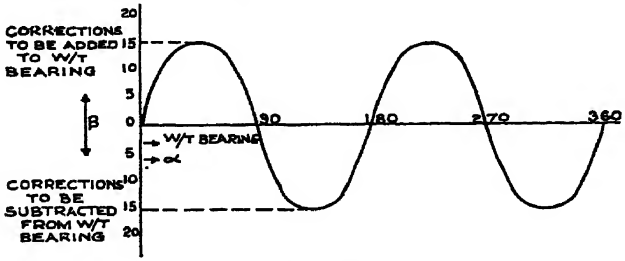


Fig. 93.

In practice the quadrantal correction curves are not as regular as the theoretical one drawn, due to :—

Influences on Q.E. Curve.—
(*a*) Position of the frame relative to the fore and aft line of the ship.
(*b*) Unsymmetrical distribution of the metal masses on the ship, e.g. funnels, ventilators, etc.

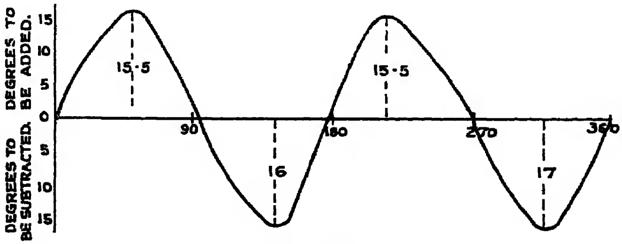


Fig. 94.

A typical curve for a ship on which the metal masses are exceptionally regular is shown in Fig. 94.

The curve reproduced in Fig. 95 represents an exceptionally interesting case.

It was taken on a ship where the frame was—

(1) 2 ft. to port off the fore and aft line, and

(2) 15 ft. from the funnel and 12 ft. from two symmetrical ventilators, which were all aft of the frame, and one in the fourth quadrant forward of the frame.

The following two facts emerge :—

(1) When the frame is off the fore and aft line it acts as though the whole curve were moved on a new ordinate.

(2) The influence of the iron masses, viz., the funnel and ventilators, has resulted in larger deflections in the third and fourth quadrant than in the first and second quadrant.

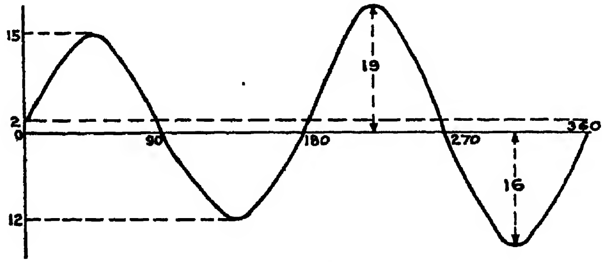


Fig. 95.

The maximum	deflection	in	first quadrant	is	15°.
,,	,,	,,	second ,,	,,	12°.
,,	,,	,,	third ,,	,,	19°.
,,	,,	,,	fourth ,,	,,	16°.

If the whole curve were moved $1\frac{1}{2}°$ higher, there would be equal deflections in quadrants 1 and 2, and also in quadrants 3 and 4, the maximum deflections being greater in 3 and 4, owing to the proximity of the funnel and the ventilator in No. 4 quadrant.

Deflection due to Different Values of Wave-length used in Calibration.—Consider the curve shown in Fig. 96.

It has been shown that β varies as $\sin 2\alpha$ (Fig. 93).

This may be written $\beta = A \sin 2\alpha$,

where β = deflection, A = maximum deflection,

α = angle from the ship's fore and aft line.

If a theoretical curve is plotted for the equation $\beta = A \sin 2\alpha$, where $A = 10°$ and $A = 12°$, a marked difference occurs in the two values of deflections as indicated in Fig. 96.

The curve a is a typical curve for 1000 m.
,, ,, b ,, ,, ,, 600 m.

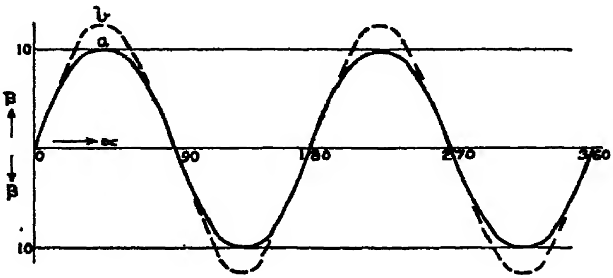


Fig. 96.

This illustrates the fact that the deflection due to the ship's mass is *greater* for *shorter* waves than for longer waves. Thus the set must be calibrated on wave-lengths actually to be used in practice, i.e. if a set is to be used on 600 m. it should be calibrated on 600 m.

In actual practice the sets are used on 600 m. for ship work and commercial coast stations, and 600 m., 706 m., 800 m., and 1000 m. on American coast and American beacon D.F. stations. Numerous tests have given the following results :—

Calibrations have been made on 800 m., and checks on 600 m. and 1000 m. have shown no appreciable error. In one particular installation calibrated on 800 m., a large number of check bearings were made on 600 m., and the maximum error was 0·4° and the mean error 0·2°.

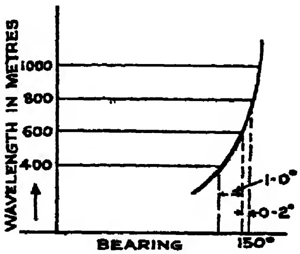


Fig. 97.

For all practical purposes a calibration on 800 m. holds for all waves from 600 m. to 1000 m., but a calibration on, say, 1000 m. must not be relied upon for, say, 450 m. A second curve for the low wave-lengths is essential.

The position is represented graphically in Fig. 97.

If 150° is the true bearing for 800 m., then the calibration

error is very small for all wave-lengths above this value. For 600 m. the mean error due to a calibration on 800 m. is about 0·2°. For 400 m. and below a calibration on 800 m. is not accurate.

Method of Determining the Quadrantal Error Curve. It is not possible theoretically to determine the Q.E. of any ship.

After a large amount of experience it is possible, in many cases, to give the approximate maximum deflections of the quadrantal error curve, but although this knowledge serves as a valuable guide in calibrating, the actual measurements must be made by comparing the wireless bearing against accurate visual observation.

In some cases it is possible to obtain a fair degree of accuracy by taking wireless bearings on a fixed station and plotting the position of the ship's course relative to this station on the chart. This method, however, should not be used if it is possible to carry out the calibration by using a transmitter on a tender.

It should be remembered that a direction-finder is an instrument of precision, and fully reliable if properly used. The results obtainable from the instrument depend on the accuracy and care with which the quadrantal error curve is made, and even if time and trouble have to be spent in obtaining a correct Q.E., the quality of the results obtained well repays the labour expended. The installer should not be satisfied until the Q.E. is absolutely reliable.

Method of Calibrating, using a Mobile Transmitter.—The best method of obtaining the data necessary for the Q.E. curve is as follows :—

A tender or tug is fitted with a small transmitter—preferably a C.W. or I.C.W. set—capable of sending out about 5 to 10 watts aerial energy.

The ship which is to be calibrated is held at anchor, and the tender or tug caused to steam slowly around her at about 5 to 6 knots. The wireless bearings are observed at least every 10°, or, better still, every 3° or 4°, the limiting factor being the speed at which accurate visual observations can be taken. Simultaneously with the wireless bearing, a visual bearing is taken from the ship on to the tender. This visual bearing is always taken relative to the ship's fore and aft line. It is best to take

this bearing from the standard compass platform and the bearings should be read on the scale outside the compass and relative to the "*lubber line*."[1] Observation is facilitated by making use of the azimuth mounted on the standard compass ring. The standard compass, in fact, should be used as a *pelorus*.

Where provided on a ship, the pelorus should be set on the ship's fore and aft line, and bearings of the tug should be read relative to that line.

Certain ships are provided with a special form of pelorus, which is connected to the gyroscopic repeater, and gives bearings relative to the true north. In order to use this type of instrument, the repeater dial should be disconnected from the gyro-

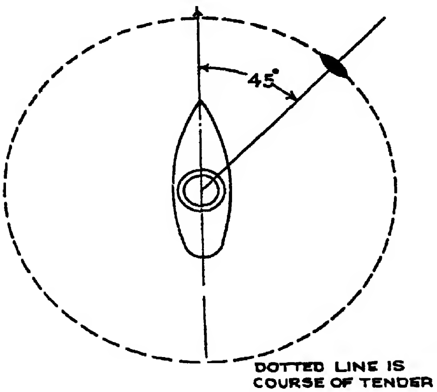


FIG. 98.

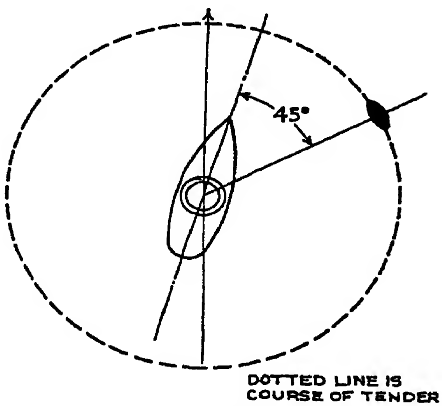


FIG. 99.

scopic compass and adjusted with the 0°-180° scale readings on the ship's lubber line, in which case the bearings of the tender relative to the ship's fore and aft line are read on the 360° compass.

Figs. 98 and 99 give an idea of the method of calibration, as well as of the method of reading the visual angle between the ship's fore and aft line and the tender.

The scale of the pelorus is greatly magnified, and no matter how the ship swings on its anchor, the angle read on the pelorus is always the angle between the tender and the ship's fore and

[1] *Lubber Line.*—This is the line on the ship's standard compass which is set on the ship's fore and aft line, and any bearings taken relative to the lubber line must in consequence be relative to the ship's fore and aft line.

aft line, i.e. the angle read is always a relative bearing to the ship's fore and aft line.

If no pelorus is available, then the following readings should be taken simultaneously :—

(1) W/T bearing.

(2) Angle of the tender relative to the standard compass, i.e. magnetic north.

(3) Ship's head relative to magnetic north.

From (2) and (3) the visual angle between the ship's fore and aft line and the tender is obtained. This entails a tedious calculation for each bearing.

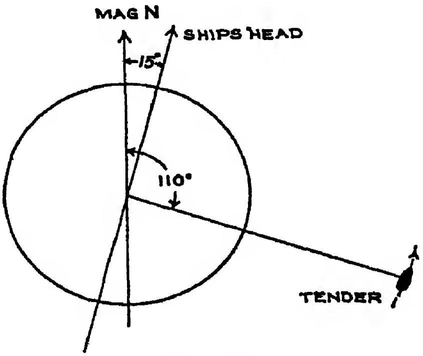


Fig. 100.

In the example illustrated in Fig. 100, ship's head = N. 15 E. = 15° from magnetic north. The visual bearing of the tender = S. 70 E. = 110° from magnetic north. Hence the angle between the ship's head and the tender = 95°.

Arrangements should be made to connect up the visual observation point on the standard compass platform to the wireless cabin by means of a bell, controlled from the wireless cabin. As the operator reads the bearing he presses the bell, and the visual observer (generally the ship's navigating officer) reads the visual bearing. Bearings should be read on the 360° compass, i.e. N. 20 E. = 20° ; S. 15 W. = 195°, etc.

Tables should be compiled by the wireless operator and the visual observer from the bearings taken. These tables give the deflection of the wireless bearing, and from this the necessary quadrantal error curve can be plotted.

A typical form of table is reproduced in Fig. 101.

NUMBER OF BEARING	WIRELESS BEARING	VISUAL BEARING	DIFFERENCE
1	0	0	0
2	10	12	+2
3	20	24·5	+4·5
4	30	37	+7
5	40	51	+11
6	50	60	+10
ETC	60	66	+6

Fig. 101.

Great care must be taken to keep strictly to the *sequence*

of bearings, and if the visual operator cannot take a bearing on hearing the bell ring, a mark should be made on his bearing table indicating that a bearing has been missed. It is very advisable to keep in close touch with the visual observer every three or four bearings, in order to ensure that the sequence is properly kept. If the sequence is lost, the whole calibration is rendered futile.

The wireless operator must make sure that the main aerial

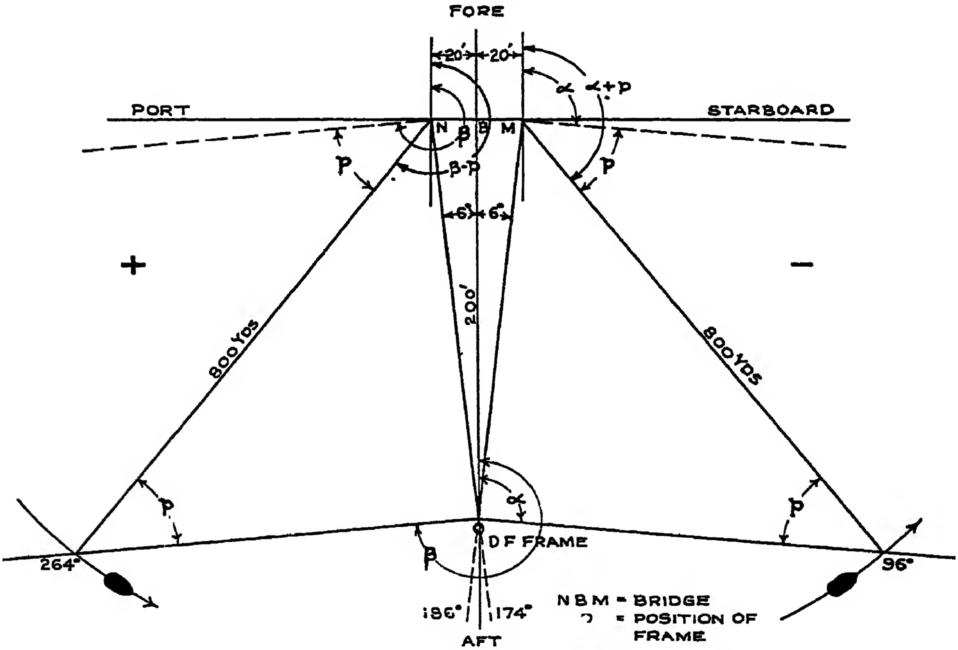


Fig. 102.—Specific example of parallax.

is broken on calibration, and when taking all wireless bearings. Otherwise, bearings off the fore and aft line will be drawn towards the fore and aft line of the ship, and errors will occur.

Parallax Errors.—Errors due to parallax must be carefully avoided, or at least reduced to a minimum. A certain amount of parallax error must always be present when the frame of the direction-finder and the visual observation point are separated from one another. If the distance between the D.F. frame and the observation point is less than 10 yds., and the tender is 1 mile from the ship, the parallax error is negligible.

It may be of interest to consider the specific case of parallax error which was experienced on one of the world's largest passenger liners.

Fig. 102 represents the actual conditions when the Q.E. was being taken.

The points of visual observation were on the bridge at M and N. Owing to obstruction, no visual observations could be made on the fore and aft line.

The W/T angle observed from 0 is α.

The visual angle observed from M is $\alpha + p$, where p is the parallax error angle.

Obviously, the parallax error is nil along the fore and aft line, and reaches a maximum athwartships. Moreover, this error is negative from ahead to stern, i.e. the visual angle read, namely $(\alpha + p)$, is greater than the W/T angle α by the parallax angle p, i.e. angle p must be subtracted from the observed angle. From stern to ahead, the visual observer reads angle $(\beta - p)$, while the W/T angle is β, so that the parallax error is positive, and must be added to the observed bearing to obtain the correct angle. In the example above, the angle between the fore and aft line and the visual observation points on either end of the bridge was 6°.

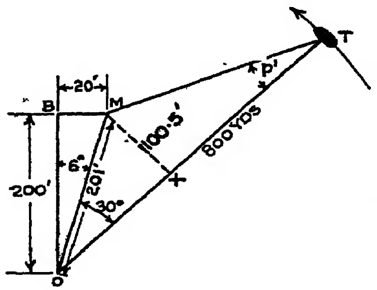


Fig. 103.

Therefore the maximum parallax occurred at 6 + 90° = 96° and 270° – 6° = 264°.

Assume now that the tender is 800 yds. away (see Fig. 103). Then

$$\sin p = \frac{201}{2400} = 0{\cdot}084 \text{ and } p = 4{\cdot}8° = 5{\cdot}0° \text{ approx.}$$

Therefore, $p = 5{\cdot}0$ at 90° from line M.O.

Now consider angle MOT = 30°.

Then $$MX = 100'.$$

$$\sin p' = \frac{100}{2400} = 0{\cdot}0415.$$

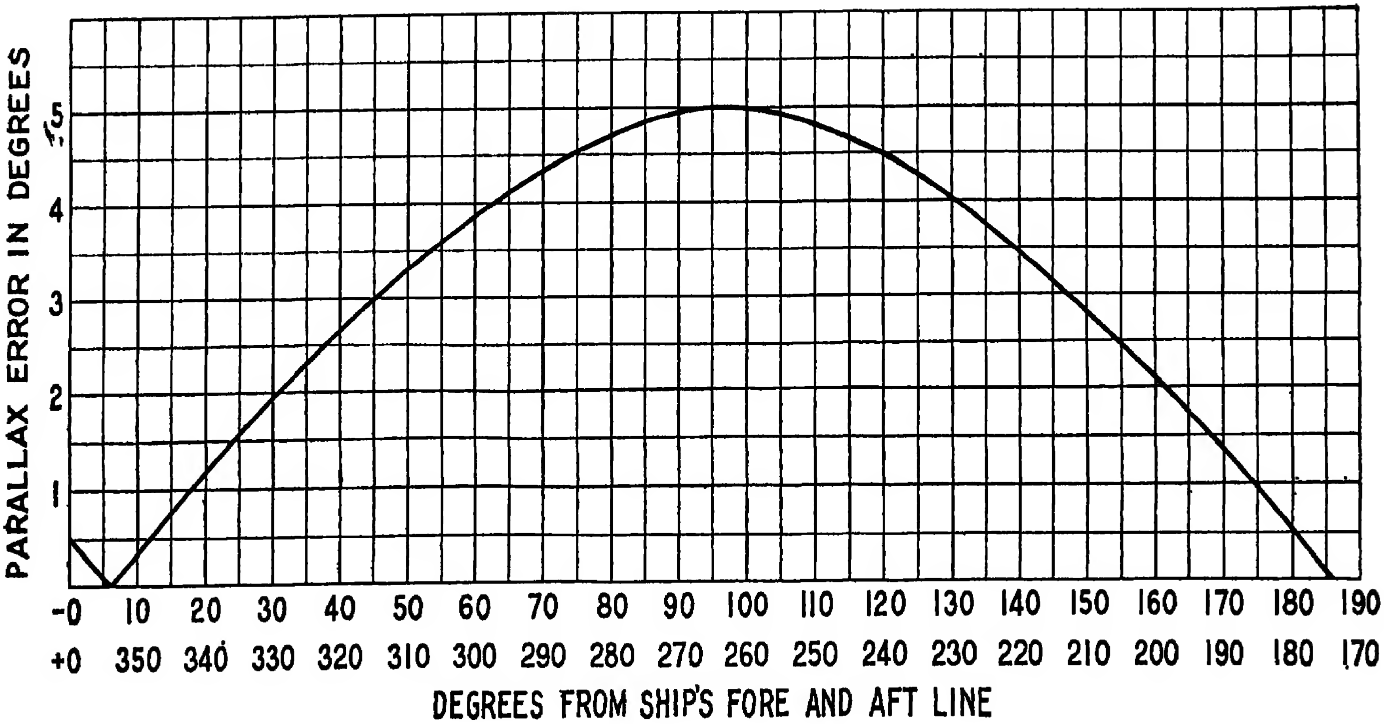


Fig. 104.

[To face page 103.

Therefore, $p' = 2° \ 24'$.
$= 2{\cdot}4°$.

For angle MOT $= 45°$, MX $= 142'$.

Then we get $\sin p'' = \dfrac{142}{2400} = 0{\cdot}059$ and $p'' = 3° \ 24' = 3{\cdot}4°$.

The values of the parallax errors are thus as follow :—

5·0°	for 90°,	i.e. for	$(90 + 6) = 96°$	and	$(360° - 90° - 6°)$	$= 264°$.
3·4°	,, 45°	,, ,,	$(45 + 6) = 51°$	,,	$(360° - 45° - 6°)$	$= 309°$.
2·4°	,, 30°	,, ,,	$(30 + 6) = 36°$	,,	$(360° - 30° - 6°)$	$= 324°$.
0°	,, 0°	,, ,,	6°	,,	$(360° - 6°)$	$= 354°$.

By plotting these values graphically, a parallax error correction curve is obtained which can be applied to the visual observations so as to get the true visual observations without parallax error. This is shown in Fig. 104.

From all visual readings from 0° to 180° subtract parallax error.

To all visual readings from 180° to 360° add parallax error.

For example, visual observation	=	30°	306°
parallax	=	− 2·4°	+ 2·4°
Corrected visual without parallax	=	27·6°	308·4°

A correction chart for maximum parallax errors for definite base lines over distances up to 5 miles is given in Appendix V.

Simple Rules for Estimating Parallax Errors.

(1) First measure the distance between the D.F. frame and the point of visual observation (say, x feet). This is the base line.

(2) Determine through direct observation the direction of the base line joining the D.F. frame and the point of visual observation. In this direction the parallax error angle p is equal to zero ($p = 0$).

(3) The angle p is a maximum at an angle of 90° to the line joining the base line, and can be sufficiently approximated from the formula—

$$p_{90} = \frac{57x}{y}$$

where y is the distance between the ship and the observed point.

(4) $\frac{3}{4}p_{90}$ lies at 50° and 130° from the base line; $\frac{1}{2}p_{90}$ lies at 30° and 150° from the base line.

(5) Consider one stands in the position of the D.F. frame, looking in the direction of the visual observation point, then

(*a*) In the right hand semi-circle p is minus.
(*b*) ,, ,, left ,, ,, p is plus.

(6) Visual observation $\mp p$ = corrected visual observation, the sign of p being dependent on (5).

Checking the Quadrantal Error Curve.—Every opportunity should be taken to check the Q.E. curve, but the checks should only be made when the exact position of the ship is known. It should be remembered that even with the best navigators possible, it is no easy matter to place a ship within 0·5°, even by direct visual observation. Consequently, checks should, wherever possible, be made when visual observations are practicable. In making these checks the following points should be very carefully borne in mind:—

(1) Checks should be avoided at dawn and dusk (see Chapter X.).
(2) Checks should be avoided in angles of bad bearing (see Chapter X.).
(3) Checks should be avoided in cases where coastal refraction is possible (see Chapter X.).
(4) Checks should be carried out in all possible cases across the sea, and not on a station to which the waves have to travel across land and sea.

Experience indicates that when a check is being made on a large W/T transmitting station within visual range, errors are liable to occur unless the visual observations are made on the centre of the aerial system. The transmitting house is the best place on which to make the visual observations.

An excellent method of checking the Q.E. is to ask the W/T operator on a passing ship within accurate visual range to transmit a few dashes on low power as he approaches, and passes, and recedes from the ship on which the D.F. is installed.

Visual and W/T checks can be made simultaneously and recorded on the Q.E. curve.

Great caution should be taken not to change the Q.E. on a few isolated bearings. The best method is to record all check

bearings on the Q.E. graph, and then observe how further checks lie relative to the Q.E. curve. Should a number of check bearings ultimately indicate that the Q.E. curve is inaccurate, then the latter must be amended accordingly. Experience has shown that the Q.E. curve usually requires very little amending, especially if no parallax errors have occurred in the original calibration and the calibration was carried out by experienced observers.

The Effect of Compass Errors on Wireless Bearings.—As is explained in Chapter VIII., the bearing of a station relative to true north is obtained by adding the W/T bearing, i.e. the bearing of the station relative to the ship's fore and aft line, to the corrected compass bearing, the latter being obtained by the compass reading ± deviation ± variation. Consequently, great care should be taken to get an accurate reading of the compass.

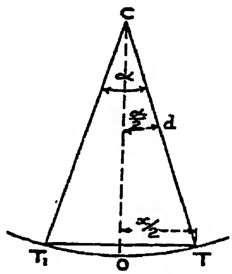


Fig. 105.

In the case of a gyroscopic compass, no corrections are necessary.

With the aid of Fig. 105, let us consider the error in computing the distance due to an error in reading the compass.

If C = observation point,
T = true position of the observed object ⎫ let distance
T′ = False „ „ „ ⎭ TT′ = x.
Therefore α = angle of error on position T.

Then $$\sin\frac{\alpha}{2} = \frac{\frac{x}{2}}{d},$$

i.e. $$\frac{x}{2} = d\sin\frac{\alpha}{2},$$

or $$x = d\sin\alpha.$$

Now. $$\sin 1^\circ = 0{\cdot}0175$$
and $$60 \times 0{\cdot}0175 = \text{approximately } 1.$$

Thus is derived the simple rule that at 60 miles an error of 1° in the compass reading gives an error in the ship's position of 1 mile, or an error of 1 km. at 60 km. distance.

To avoid the chance of error, or to minimise it as much as

possible, it is recommended that in all cases where the compass is being used to take the ship's head at the moment of taking the W/T bearing, three or four bearings be taken in rapid succession, and a mean value of the D.F. and compass readings used. This is specially advantageous when a ship is rolling in a heavy sea or slightly changing its course, as the compass, owing to its inertia, always lags slightly behind the true bearing reading.

It should be remembered that the deviation of the magnetic compass is by no means a constant. For example, if a ship is travelling on a long west course, then it builds to starboard a north pole and to port a south pole, i.e. the deviation is changed, and the error may be quite 1° or 2°, or even greater. This emphasises the importance of obtaining astronomical deviation checks as frequently as possible, especially if working on the magnetic compass and not on the gyro compass.

The Influence of Ship's Metal Masses on the W/T Bearings.—The influence of the ship's hull and general masses has already been dealt with (see p. 93).

Now consider the effect of the local structures on the ship's deck, e.g. main aerial, ventilators, funnels, and derricks. Provided that these metal structures are below the level of the frame ring base, they have no influence worth considering on the bearing.

The **main aerial** must always be broken when a bearing is being taken. In order to prevent a bearing being taken while the ship's aerial is in circuit, a warning lamp is arranged to light up when the ship's aerial circuit is broken on the main switch (see Figs. 88 and 89). The operator then knows that an accurate bearing can only be taken when the warning lamp is burning. If the main aerial is not broken, the minimum is generally woolly and inaccurate. The influence of the main aerial remaining in circuit is to increase the deflection of the W/T waves caused by the ship's metal mass, i.e. the maximum deflection is greater. As much as 6° swing on a bearing has been observed on switching the main aerial into circuit. The maximum influence on the deflection of the incoming wave naturally occurs when the main aerial is tuned to the same wave-length as the incoming wave.

In the case of battleships or vessels employing more than

one aerial, arrangements must be made for breaking *all* aerials before a wireless bearing is taken.

Derricks, Stays, etc.—All derricks form small closed circuits to earth. Arrangements should be made that the frame base is, if possible, above these closed loops formed by the derricks, the cross-stay and the deck. Usually the derricks are at such a distance from the fore and aft line of the ship that their influence is small. It should also be remembered that when a ship is calibrated the derricks are in a fixed position, and the deflections due to the closed loops formed by the derricks are accounted for in the Q.E. Should, however, the derricks be removed after the Q.E. is taken, check bearings should be made in the particular quadrant where the derrick was, in order to correct the Q.E.

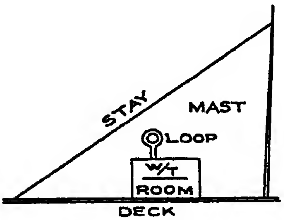


Fig. 106.

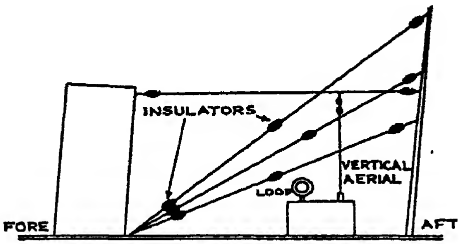


Fig. 107.

Stays.—When choosing the position of the D.F. frame, nearness to stays should be avoided as much as possible. It is specially advised to avoid placing the frame directly under the stay as in Fig. 106. Here is shown a completely closed loop formed by the stay, the steel mast and the deck. If the natural wave-length of this loop approaches either the wave-length or a harmonic of the wave-length being received, then serious errors are liable to occur. In one particular case the actual deflection observed was 45°.

Insulation of Stays.—If no other position is available, then the trouble can be surmounted by breaking up the stay with insulators. An actual case is illustrated in Fig. 107. In this case the influence of the closed loop formed by the stays was entirely eliminated.

Theoretically, it is only necessary to break up the loop at one point by means of compression insulators. It is best,

however, in case the stay has a natural frequency which resonates either to the fundamental, or a harmonic of the incoming wave, to break it up into short lengths as depicted in Fig. 107.

The same applies to any triatics passing over the frame and particularly to the triatic from which the vertical aerial is suspended.

Frequently, if the set is on the bridge, steel whistle lanyards run within 6 or 8 ft. of the frame.

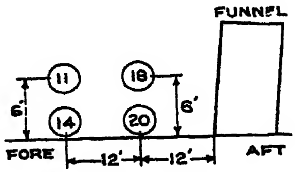


Fig. 108.

These should be broken by small compression insulators spliced into the lanyards.

Funnels.—If the frame is forward of the funnel and within 20 ft. thereof, the maximum deflection of the Q.E. is greater. From the actual tests reproduced in Fig. 108, it will be observed that the further from the funnel the frame is situated and the higher above the deck the less is the deflection.

Ventilators.—These are very similar to funnels in their influence, especially if they are (1) within 15 to 20 ft. of the frame, and (2) above the level of the frame base.

Ventilators are by far the most difficult masses one has to contend with, as they are moving masses of iron in the near vicinity to the frame. Provided that the ventilators are of symmetrical type, their influence is allowed for in the Q.E.

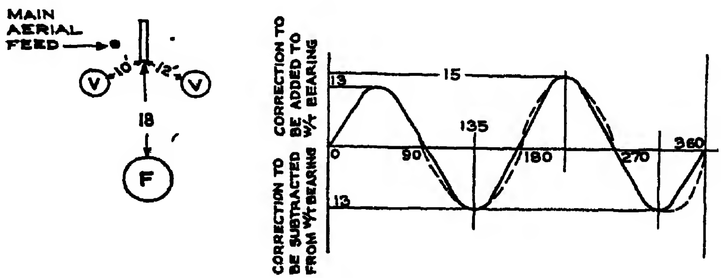


Fig. 109.

An excellent example of the effect of two ventilators is shown in the accompanying Q.E. taken on S.S. "Gatun" (Fig. 109).

In the normal installation the curve would have been as

indicated by the solid line, but actually the curve was as shown by the dotted line.

Here it is seen that the effect is to increase the deflections and to flatten the Q.E. A noticeable effect is that due to the main aerial down leads which have caused a flattening in the fourth quadrant of about 2° to 3° between 300° and 360°. The maximum deflection of 15° in the third quadrant against 13° in the first, second, and fourth quadrants is due to the effect of the funnel and the port ventilator.

Moving Ventilators.—This is undoubtedly the most difficult problem to be faced if the moving ventilators are large, within 12 to 20 ft. of the frame, and unsymmetrical.

A striking example of the influence of ventilators of this type is shown in the accompanying Q.E. (Fig. 110).

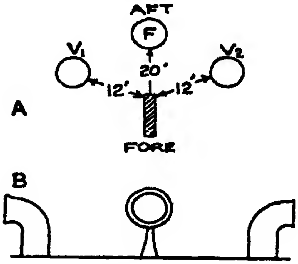


FIG. 110A.

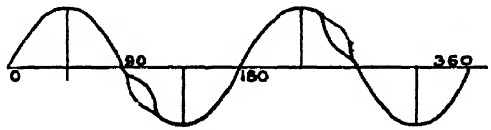


FIG. 110B.

F = funnel.

V_1 and V_2 are moving ventilators shown in plan and elevation. The lips in this particular case were rotatable and unsymmetrical and, moreover, were above the level of the bottom of the ring.

The solid line in the diagram refers to the Q.E. with the ventilator lips facing forward and the dotted line with the ventilator lips facing aft. The difference noted was 5°.

After a number of observations, and noting the position of the lips, it was easy to get the correction within 0·5°.

In the case of rotating ventilators it is best to mark the position of these when the Q.E. calibration is made, and when bearings are taken every effort should be made to have the ventilators back in this position when D.F. bearings are being taken.

General Conclusions Relative to Q.E. Curves.—The general shape of the curve is governed by the distribution of the ship's metal mass relative to the situation of the frame on the ship.

For example, if we consider a frame placed as in Fig. 111, we get the following.

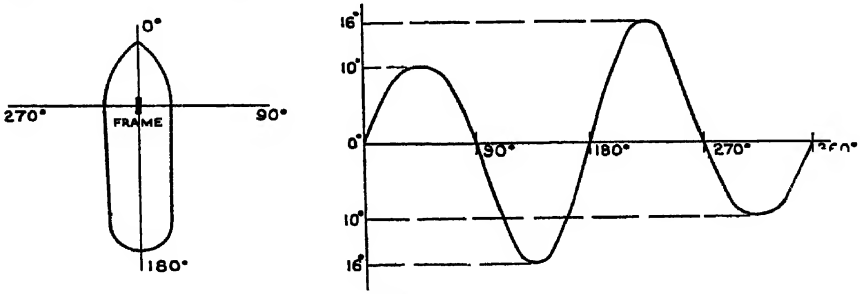


Fig. 111.

In 1st and 4th quadrants the metal masses are relatively small compared with those in the 2nd and 3rd quadrants, and consequently the Q.E. corrections in the first and fourth quadrants are smaller than in the second and third quadrants, as shown in figure.

Now consider the frame as above, but moved off the ship's centre line as in the sketch below.

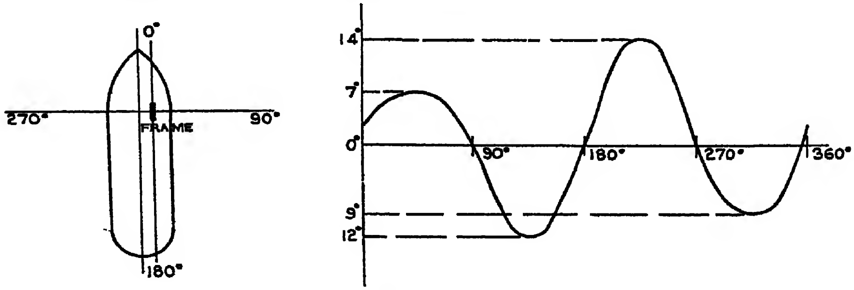


Fig. 112.

The distribution of the ship's metal mass relative to the frame is first quadrant, small mass; fourth quadrant, fair mass; second quadrant, larger mass; third quadrant, largest mass.

The general form of the curve would be as given in Fig. 112.

The above does not take into account any local structures. e.g. stays, derricks, etc., which, being in the near vicinity of

the frame, might alter the general configuration of the given curves. However, an excellent general idea of the shape of the curve can be obtained in this manner.

It is to be noted that the higher the frame is raised above the ship's metal masses, the smaller is the maximum angle of deflection.

In one special case of a fairly large oil tanker (8000 tons) the frame was mounted very high above the metal deck above the chart-room. The result was that although careful checks were made, no Q.E. curve was necessary, and bearings were exceptionally sharp and accurate.

Calibration of Coast Stations.—D.F. sets on coastal points can be most easily calibrated as follows :—

Imagine the set installed on a site as in Fig. 113.

A method of visual observation is arranged at the D.F. station. An azimuth or theodolite will be satisfactory.

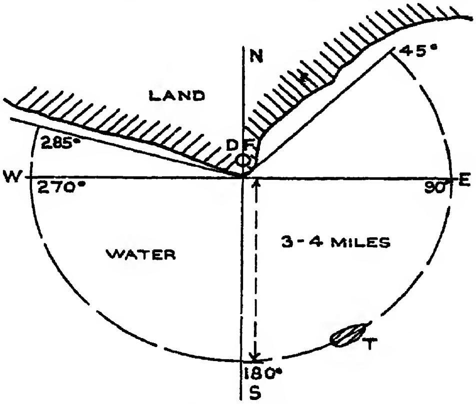


Fig. 113.

The azimuth is set on the true north and south line so that 0°-180° is true north and south.

A tender T fitted with a small transmitter is caused to steam slowly along a circular course at about 3-4 miles from the D.F. set. Simultaneous bearings are taken by W/T and visual observation, and the quadrantal error curve is plotted as shown in Chapter VI.

If the set has to be used for taking bearings on a number of different wave-lengths, e.g. 600-800-1000 m., calibrations should be made on each wave-length and separate Q.E. curves drawn for each wave-length (see p. 97).

When actually taking the Q.E., the transmitter on the tender can be caused to transmit continuously, and bearings taken every 2° to 5°. Provided that two series of observations on each wave-length are taken, very great accuracy can be achieved in this way.

This station can be calibrated in the directions over land as described in the next paragraph.

Calibration of a Land Station.—Imagine a D.F. station erected on a site such as shown in Fig. 114.

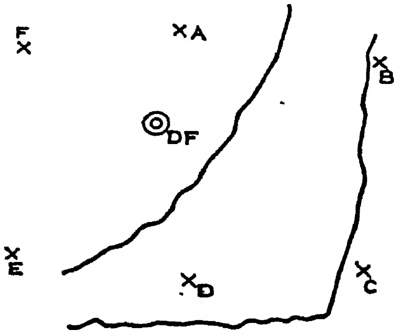


Fig. 114.

Firstly, the frame should be carefully set in the true north and south position (see next paragraph). Then the calibration can be carried out in one of the following two ways.

If a really large-scale ordnance survey map of the surrounding district is available, a portable station may be sent out on a motor car to known sites —A, B, C, D, E, F, etc.—which can be carefully laid off on the map, and provided the position of the D.F. frame is accurately known, bearings can be laid off to these positions. The difference between these map bearings and the observed W/T bearings on the D.F. set enable the Q.E. curve to be drawn.

The second method is to obtain maps, either Mercator or gnomonic of the district, covering the positions of known W/T stations. These positions are accurately laid off relative to the D.F. frame position on the chart. A comparison is made of the W/T bearings and the map bearings. Knowing these, the Q.E. curve for the station can be plotted.

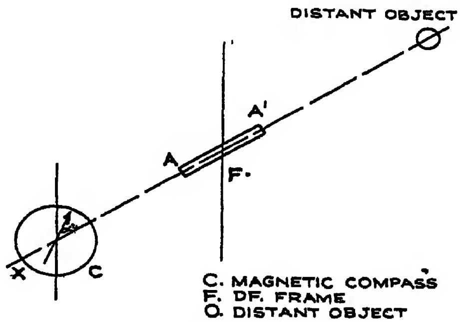


Fig. 115.

Method of Setting a Frame in the True North and South Direction.—Set the frame so that the two extreme points AA′ on the one edge cover any distant object O. Now, using a compass sight along the line XAA′O, note the angle α, i.e. the angle between the line of sight on the frame and on the distant object relative to magnetic north. Let this angle be, say, 52°. Now consider the magnetic

variation of the place. If this be west subtract, and if east, add. Assuming the magnetic variation to be 13·5° W., then the angle of the frame relative to true north is $52° - 13{\cdot}5° = 38{\cdot}5°$.

Now, if signals from true north are required to come in at zero on frame, the latter must be placed so as to lie on a line 90°-270° from true north. To do this, it must be set at the apparent reading of $38{\cdot}5° + 90° = 128{\cdot}5°$.

Leaving now the frame fixed the whole while, adjust the pointer to read 128·5°, and clamp the pointer scale in this position. If we then release the frame, it will lie on the line 90°-270° from the true north, and the bearings from true north will be zero.

CHAPTER VII.

MAPS.

Before being able to apply direction finding to navigation in an intelligent manner, it is essential to understand thoroughly the methods of representing the earth in map form.

The Earth.—The earth rotates on its axis N.-S. On account of the centrifugal force due to this rotation, the earth is flattened towards the poles N. and S., thus giving it the shape of an "oblate spheroid." As this flattening is only $\frac{1}{200}$th of the earth's diameter at the equator, it can be neglected for all practical purposes of navigation.

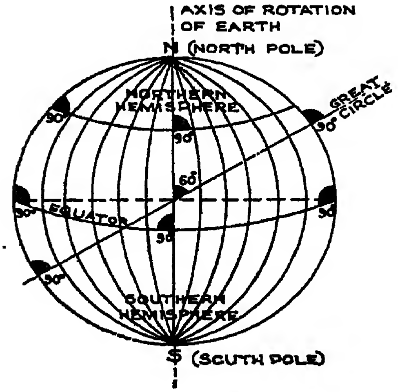


Fig. 116.

The poles N. and S. are known as the north and south poles respectively.

The equator is a great circle joining points on the earth's surface equidistant from the poles, and divides the earth into two hemispheres. That lying between the equator and the north pole is the *northern hemisphere*, and that between the equator and the south pole is the *southern hemisphere.*

The position of any place on the earth's surface is denoted by its latitude and longitude.

Latitude.—The latitude of any place is its distance from the equator, north or south.

Each hemisphere is divided into 90 degrees of latitude, the poles being respectively 90° N. and 90° S. latitude. The parallels of latitude are circles drawn parallel to the equator, and subtend definite angles at the earth's centre ; thus latitude

40° subtends an angle of 40° at the earth's centre (see Fig. 117) with the plane of the equator.

All latitudes north of the equator are called *north latitudes* and shown by letter N., e.g. 40° N.

All latitudes south of the equator are called *south latitudes* and shown by letter S., e.g. 21° S.

Each degree is divided into 60 *minutes*, shown thus: 1′. Each minute is again divided into 60 *seconds*, shown thus: 1″. Thus the latitude of London is stated as 51° 0·2′ 0·45″ N.

Longitude.—This is the distance east or west of a known great circle through an arbitrarily fixed meridian, for which purpose the meridian through the Royal Observatory, Greenwich, is employed. All positions on the earth's surface are measured east or west of this zero great circle. The great circles of longitude converge through the poles, and are called meridians of longitude. Thus the longitude of a point on the earth's surface is the angle subtended at the earth's centre by the great circle through that place and by the great circle through Greenwich.

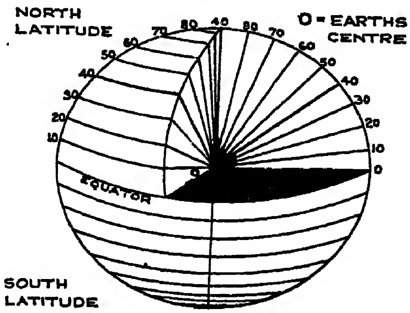


FIG. 117.

As with parallels of latitude, the meridians of longitude are divided into minutes and seconds.

Meridians are stated from 0° to 180° east and 0° to 180° W.

Thus the longitude of a point may be written as 10° 52′ 42″ E.

Great Circles.—A great circle is a line on the earth's surface making the shortest distance between two points on the earth's surface. In other words, a great circle is the intersection of the earth's surface with any plane drawn through the earth's centre.

Any number of great circles may be drawn on the earth's surface.

The equator is the only parallel of latitude which is a great circle, because it alone passes through the earth's centre. All meridians of longitude are examples of great circles.

It should be noted that a great circle cuts the successive meridians at different angles (see Fig. 116).

The difference between the angles of intersection of a great circle and two successive meridians is known as the convergency.

As all wireless waves travel over the earth's surface in great circles, it is very important that a clear conception of the meaning of great circles should be obtained and kept in mind when using charts for direction-finding purposes.

Relationship between Latitude and Longitude.—Each degree of latitude is divided into 60 minutes. The linear distance on the earth's surface corresponding to 1 minute of arc of meridian (i.e. 1 minute of latitude) is known as a *nautical* mile. As the earth is not a perfect sphere, this distance varies slightly in different latitudes. It is 6045·7 ft., or approximately 1852 metres, at the equator.

The variation of the minute of latitude varies with the cosine of the latitude. We have in triangle COM,

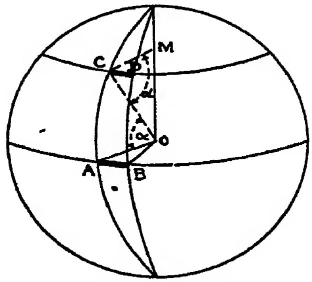


Fig. 118.

$$CM = CO \cos \alpha.$$
$$CO = AO \text{ (both earth's radii).}$$
$$\therefore CM = AO \cos \alpha,$$

i.e. the radius of a parallel of latitude = radius of the equator multiplied by the cosine of the latitude. As the circumference of a circle is proportional to the radius, we have the

$$\text{Arc at any parallel of latitude} = \text{arc at equator} \times \cos \alpha.$$

Therefore the minute of latitude at any parallel equals the minute of latitude at the equator multiplied by the cosine of the latitude.

To endeavour to produce a model of the earth's surface sufficiently accurate for navigation purposes is quite impracticable. The only method of reproducing the earth's surface accurately and without distortion would be by means of a globe, and even a small-scaled globe would be useless, especially for accuracy near a coast line. Consequently the earth's surface is reproduced in the form of a flat surface in maps of different projections.

The two commonly met with in navigation are—

(*a*) *Mercator* projection.
(*b*) *Gnomonic* projection.

Mercator Charts.—This is the commonest type of chart met with in D.F. work, and almost universally used for navigation.

The best way to visualise this type of chart is to imagine a transparent globe to represent the earth, and surrounding this globe to imagine a cylinder, as in Fig. 119.

Imagine a light at the point O, the centre of the earth, and consider the projection of the globe on to the cylinder.

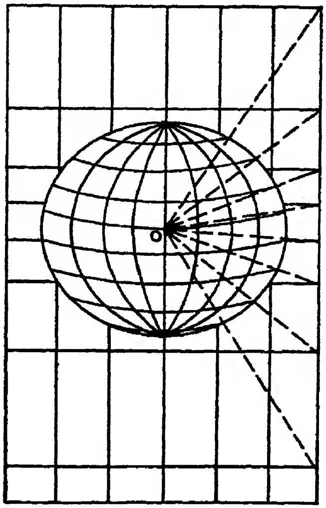


Fig. 119.

In maps produced by this method, the surface of the earth is drawn just as it would appear if projected on the surface of the cylinder.

It is obvious on a projection of this kind that—

(1) All meridians of longitude are straight lines equidistant from one another.
(2) All parallels of latitude are straight lines parallel to the equator. The distances of successive parallels of latitude vary.
(3) It is not possible to include the poles in this projection.
(4) A straight line drawn across the chart cuts all meridians at the same angle. It is owing to this fact that a Mercator chart is so very valuable for navigation purposes, as a ship's course can be laid off on the chart and the ship navigated to this course without continuous change of the setting of the course on the chart.

The projection would appear somewhat as in Fig. 120.

The scales of latitude and longitude are only the same at the equator, and the further a section of the surface is from the equator the more it is distorted. This can be seen from

Fig. 120. The distances N. and S. and E. and W. are very different. Consequently, any map drawn to the Mercator projection is considerably distorted.

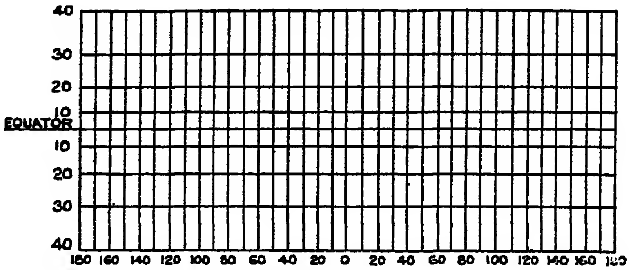


Fig. 120.

It is only possible to use a fixed scale on places on the same latitude.

The charts are, however, marked with the latitudes in the margin. These parallels of latitude are divided into degrees, each of which represents a nautical mile. Thus, to get a given distance on a Mercator chart, it is only necessary to measure the distance on the dividers and step it off on the latitude scale shown on the margin of the chart.

Gnomonic or Orthodromic Chart.—In this chart all great circles are shown as straight lines.

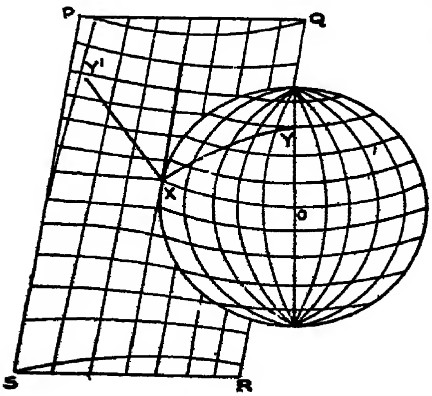


Fig. 121.

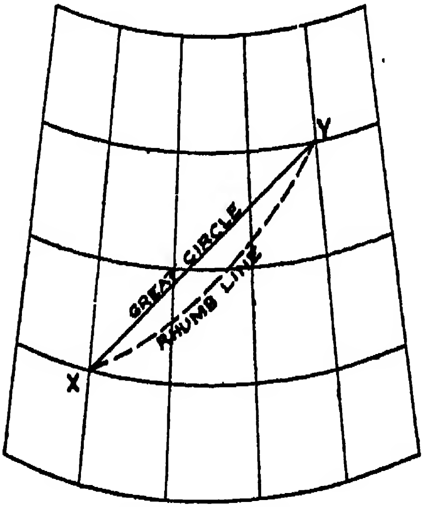
The optical method which gives a good idea of this chart can be best understood by reference to Fig. 121.

Imagine a transparent globe with a light at the centre O and a plane PQRS placed tangentially to the globe at the point X. Now all lines of longitude will be projected as straight lines. Also, a great circle XY drawn on the globe will be projected as a straight line XY^1. This is especially important from the direction-finding standpoint, as all W/T waves travel in great circles

across the globe. The point X where the plane meets the globe is called the *point of contact.*

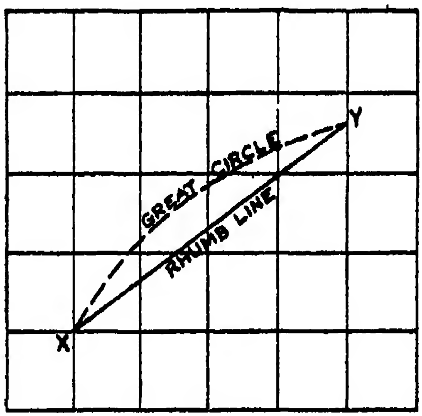
Gnomonic charts can be obtained for various positions on the earth's surface.

Rhumb Line.—Navigation is usually carried out on rhumb lines, that is, a line which cuts successive meridians at the same angle.



GNOMONIC CHART

FIG. 122.—Gnomonic chart.



MERCATOR CHART

FIG. 123.—Mercator chart.

On the Mercator chart all meridians are parallel lines, and as all rhumb lines cut successive meridians at equal angles, rhumb lines on Mercator charts are straight lines. On the other hand, on the gnomonic chart the rhumb lines are arcs of a circle.

This is shown in Figs. 122 and 123.

CHAPTER VIII.

DIRECTION-FINDING APPLIED TO NAVIGATION.

BEFORE a wireless bearing can be applied to navigation, it is necessary to know the direction of the ship's head at the moment the bearing was taken, *as all W/T bearings are relative to the ship's fore and aft line.* It is very important that this be clearly understood, as W/T bearings are not true but only relative bearings.

In cases where a ship is provided with a gyroscopic compass, the compass reading relative to the lubber line gives the bearing of the ship's head relative to true north, and consequently no corrections are necessary for deviation and variation to obtain the bearing of the ship's head relative to true north as in the case of the magnetic compass.

Gyro Compass.—Most large ships are fitted with a gyroscopic compass. This is an instrument built on the gyroscope principle, and is independent of the earth's magnetism. It consists essentially of a high-speed rotating disc driven by a small motor. This compass always indicates the bearing of the ship's head relative to true north, and no corrections are necessary for deviation or variation as in a magnetic compass. The slight necessary corrections are issued with the calibrated compass. It is usual to have a number of repeater dials worked from the main compass, and generally arrangements are made for one of these repeaters to be alongside the wireless direction-finder and fixed in such a position that the W/T bearing and the ship's head relative to true north can be read simultaneously. It should be noted that the correction curves for the gyro compass are only applicable to the Anschutz type. The Sperry and Brown gyro compasses have an automatic cosine corrector, and consequently the direction of the ship's head relative to true north is always given by the direct reading on the gyro compass dial.

In cases where a ship is only equipped with a magnetic compass, one must allow for—

(1) *Magnetic variation.*
(2) *Deviation.*

The explanation of this is as follows :—

Magnetic Meridian.—The earth acts as a magnet. Thus any magnet needle, or a system of needles as used in a magnetic compass and uninfluenced locally, takes up a definite position such that the north-seeking end points to the magnetic north pole. The line drawn in the direction taken up by a magnetic needle is called the magnetic meridian at that place.

It is obvious that this meridian varies for different points on the earth's surface. These magnetic meridians are irregular lines on the earth's surface, converging on the north pole in the northern hemisphere, which is approximately 70° N. and 97° W. and the south magnetic pole in the southern hemisphere at approximately 72° S. and 154° E.

The angle between the true north and the magnetic north at any point on the earth's surface is the *Magnetic Variation* of that place. This variation at any place differs from year to year. Its value at any place on the earth's surface can be obtained from Admiralty charts.

Deviation.—Due to the magnetism of the ship itself, the magnetic compass rarely points along the magnetic meridian, but usually slightly to the east or west of it. The angle between the magnetic meridian and the needle is the deviation. This is east if the north-seeking end of the needle lies to the east of magnetic north, and west if the north-seeking end of the needle lies to the west of the magnetic north.

Usually, the greater portion of the deviation of the compass due to the ship's magnetism can be compensated for. However, a certain amount is always present, and this must be determined and drawn out in a deviation table from which the compass reading can be corrected.

Corrected Compass.—Thus in order to correct a magnetic compass reading, allowances for variation and deviation are necessary, i.e.,

True reading = Compass reading $\pm$ Variation $\pm$ Deviation.
(True north) = (Magnetic north).

These corrections are easily applied.

Variation.—Obtain this from Admiralty chart—easterly are positive and should be added.

Deviation.—Obtain from deviation table—westerly are negative and should be subtracted.

Bearings should be converted to 360° scale. To do this, proceed as follows :—

First quadrant,	N. to E.,	no change, e.g. N. 10 E. = 10°.
Second ,,	E. to S.,	subt. from 180°, e.g. S. 30 E. = 150°.
Third ,,	S. to W.,	add 180°, e.g. S. 35 W. = 215°.
Fourth ,,	N. to W.,	subt. from 360°, e.g. N. 4 W. = 356°.

Examples.—

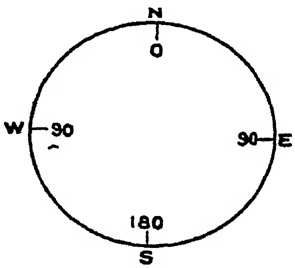


FIG. 124.

Ship's head by magnetic compass
= S. 87 E. = (180° − 87°) = 93°
Variation from Admiralty chart
= 12° E. (positive to be added) = + 12°
Deviation from correction table
= $3\frac{1}{2}$ W. (negative to be subt.) = − $3\frac{1}{2}$°

True ship's head (i.e. ship's head relative to true north) = $101\frac{1}{2}$°

Ship's head by magnetic compass
= N. 12 W. (360° − 12°) = 348°
Variation from Admiralty chart
= 10° E. (positive to be added) = + 10°
Deviation from correction table
= 2° E. (positive to be added) = + 2°

True ship's head (i.e. ship's head relative to true north) = 360° = 0°

Having now obtained the true ship's head at the instant a W/T bearing is taken, it is quite easy to obtain the direction of the transmitting station.

The D.F. set on the ship is calibrated and only *gives bearings of the transmitting station relative to the ship's fore and aft line.*

Consider the example shown in Fig. 125.

Suppose the transmitting station T gave an angle C.S.T. = 58°, i.e. W/T bearing of T relative to ship's fore and aft

line. This is insufficient information to lay off a position line through T.

If, however, at the same instant as the W/T bearing is taken the compass reading is made of the ship's head, and this reading corrected for deviation and variation, the true bearing of T from true N. is obtained. In the above example, that bearing of T is 100° from true N.

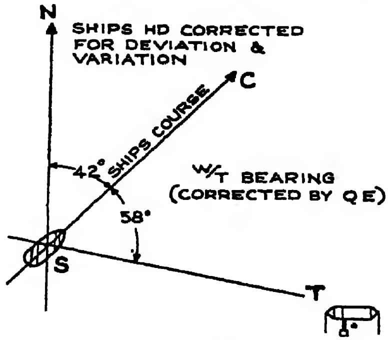


FIG. 125.

If the latitude and longitude of the station T is known (these positions can be obtained from the Admiralty List of Wireless Signals), there is now sufficient data to lay off a *position line* through T, and thus to orient the position of the ship.

In this example, it is assumed that the distance ST is less than 100 miles, and no correction has to be made for convergency.

Thus arises the rule for bearings at distances up to 100 miles, that in order to get the position of the station relative to true north,

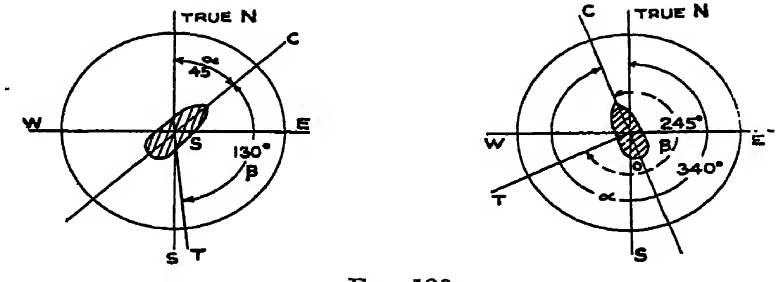


FIG. 126.

Bearing relative to True North $= \alpha + \beta$
$= 45° + 130°$
$= 175°$.

Bearing relative to True North $= \alpha + \beta$
$= 340° + 245° = 585°$
$= 585° - 360° = 225°$.

add the corrected W/T bearing to the true ship's head (i.e. ship's head relative to true north).

Therefore, true bearing of station = (W/T bearing ± Q.E.) + Magnetic compass reading of ship's head ± Variation ± Deviation.

Should the right hand of equation be greater than 360°, to obtain the bearing subtract 360° from the result.

The most usual case of W/T bearings applied to navigation occurs when the direction of a single station relative to true north is obtained as shown in Fig. 125, and the ship's position is either known from astronomical bearings, or—if these have not been possible for some time—from the ship's "estimated position" obtained by dead reckoning. This permits a position line to be laid off from the transmitting station, whose position on the chart is known to a very high degree of accuracy. This is particularly the case where a ship is provided with a gyroscopic compass, and no corrections have to be made to obtain the true north. If, however, a magnetic compass is used it is quite possible for errors to arise. This is frequently the case where no sights have been possible for a few days and the ship is steering on dead reckoning. In these cases it is quite possible for the dead reckoning positions to be inaccurate, and consequent wrong corrections for deviation and variation made. This may lead to quite large errors in the working out of the ship's position (see p. 105).

Cross Bearings.—This is quite a common case met with at sea. W/T bearings are taken on two or more known W/T transmitting stations, and the position of the ship can be fixed from these bearings.

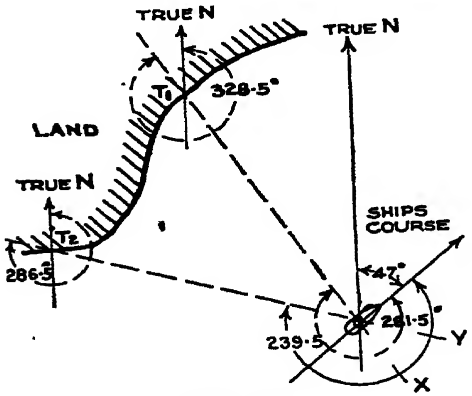


FIG. 127.

In general, it is to be noted that the stations on which cross bearings are taken give the greatest accuracy when the angle between the two stations using the ship as the apex, i.e. T_1OT_2 in Fig. 127 is 90°. Great accuracy cannot be expected if this angle is less than 30° or greater than 150°.

Two cases must be considered :—

Case I.—Where D.F. observations are taken so rapidly on the W/T stations that the distance covered by the ship between observations is negligible. This is illustrated in Fig. 127. It

is to be noted that the exact positions of the two transmitting stations are known. The navigator reads the ship's head and corrects for deviation and variation.

Example.—

Ship's head read by the magnetic compass	$= 35°$	$=$	$35°$
Variation obtained from Admiralty chart	$= 10°$ E.	$=$	$+ 10°$
Deviation obtained from correction table	$= 2°$ E.	$=$	$+ 2°$
∴ True ship's head or ship's head relative to true north		$=$	$47°$

W/T bearing of T_1 read on D.F. set	$= 285°$
Correction from Q.E. curve for 105°	$= - 3{\cdot}5°$
∴ W/T bearing of T_1 relative to ship's fore and aft line	$= 281{\cdot}5°$

Thus Bearing of T_1 relative to true north = True ship's head + Corrected W/T bearing.

$$= 47° + 281{\cdot}5°.$$
$$= 328{\cdot}5°.$$

This gives position line T_1OX from transmitting station T_1.

Further :—

W/T bearing of T_2 read on D.F. set	$= 230°$
Correction from Q.E. curve for 230°	$= + 9{\cdot}5°$
∴ W/T bearing of T_2 relative to ship's fore and aft line	$= 239{\cdot}5°$

i.e. bearing of T_2 relative to true north = true ship's head + corrected W/T bearing,

$$= 47° + 239{\cdot}5°.$$
$$= 286{\cdot}5°.$$

This gives position line T_2OY from transmitting station T_2 where these two lines intersect at O in the ship's position.

(*Note.*—In the above example the distances T_1O and T_2O have been assumed to be less than 100 miles, and therefore no convergency has been considered.

Case II.—Cross bearings on two stations with an appreciable time interval between the reading of the two bearings.

This is a case frequently met with in practice.

As in the previous case, the position line of T_1 is found and drawn as T_1A (see Fig. 128). Now imagine the ship to be travelling on an easterly course with a speed of 15 miles per hour. Then, if the bearing on T_2 is taken 4 minutes afterwards, the ship has actually travelled $\frac{15}{60} \times 4 = 1$ mile, say, to position B when the bearing on T_2 is taken.

Now lay off the position line through T_2. This gives the ship to be in the position O_1, which is incorrect.

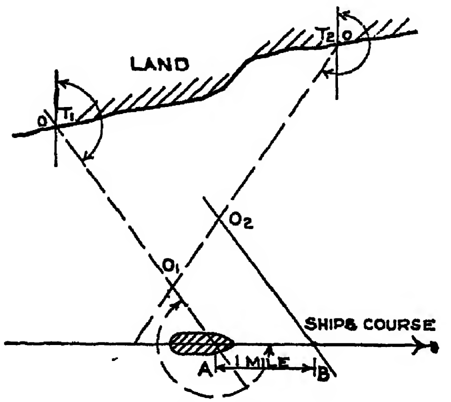


FIG. 128.

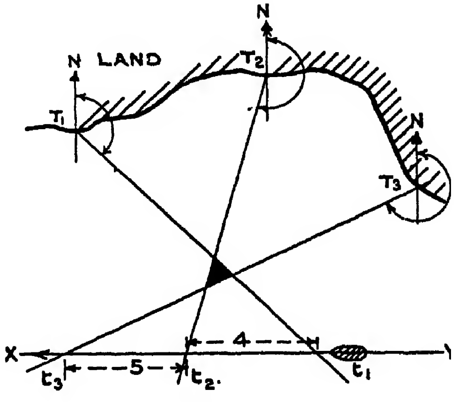


FIG. 129.

Through B, i.e. the distance travelled by the ship in the interval between the taking of bearings, draw a parallel to T_1O_1A.

Where this cuts T_2O_1, i.e. at O_2, is the ship's position.

Allowance must be made in plotting the direction of the ship's course for wind, currents, tide, etc., and the compass reading alone must not be taken to represent the course.

Case III.—Cross bearings on three fixed stations with an appreciable interval of time between the readings of the three bearings.

Suppose the ship to be travelling due west. Let the bearings on T_1, T_2, and T_3 be as follows :—

Station.	Time.	Interval between bearings.	Distance covered.
T_1	12·00	—	—
T_2	12·16	16 mins.	4 miles
T_3	12·36	20 ,,	5 ,,

Having duly corrected the bearings, i.e. both compass and W/T bearings, lay off the position lines on T_1 T_2 and T_3 as shown in Fig. 129.

This gives the *cocked hat* fix, and it is normally assumed that the centre of the "cocked hat" is the fix.

Now, knowing the sequence in which bearings were taken, and the course of the ship, lay off line XY, cutting the position lines of T_1, T_2, and T_3 in such a way that $t_1, t_2 = 4$, and $t_2, t_3 = 5$. This gives the actual positions, i.e. t_1, t_2, t_3 of the ship at the times the bearings were taken.

Note that none of these fall within the "cocked hat" position.

Case IV. Several Bearings on One Transmitting Station (a Running Fix).—This can be considered a particular example of Case II.

Assume a ship to be travelling as in Fig. 130, and a transmitting station to be situated at T.

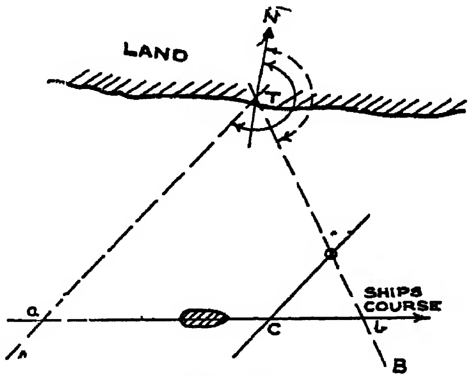


FIG. 130.

A bearing is taken which gives position line TaA. After the ship has travelled a known distance, a second position line TbB is obtained. Actually, the ship's distance travelled when the second bearing was taken is aC. Through C draw a parallel to position line TaA. This gives true ship's position at O.

The distance travelled by the ship should not be too small, in order to ensure great accuracy. Thus this method is not too reliable for long-distance bearings.

Case V.—A very convenient case, which gives both the bearing and the distance, is shown in Fig. 131.

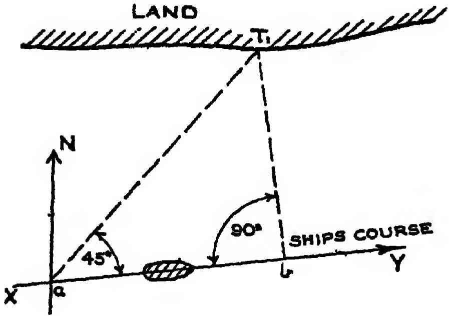


FIG. 131.

If the ship is proceeding along a course XY, and a bearing on T gives a position line Ta such that angle Tab = 45°, and a position line Tb gives angle TbY = 90°, then in the 45° triangle Tab, Tb = ab, i.e. distance travelled between bearings.

Case VI.—Changing a Course on D.F. Bearings.—If the ship is travelling on a course XY in fog, and it is known that when the transmitting station T is 160° from true north the course may be altered to round the bend, the following case arises :—

Ship's course relative to true north = 75°.

Now it has been shown that—

Bearing of the station relative to true north = True ship's head + W/T bearing + Q.E.

160° = 75° + W/T bearing + Q.E.

∴ W/T bearing + Q.E. = 85° from ship's head.

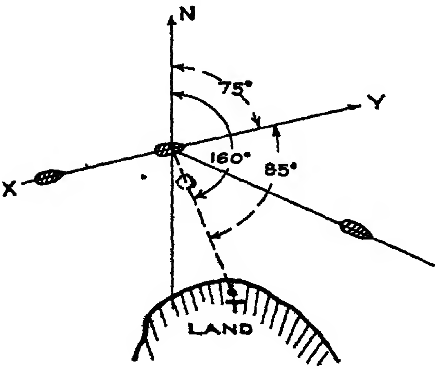


FIG. 132.

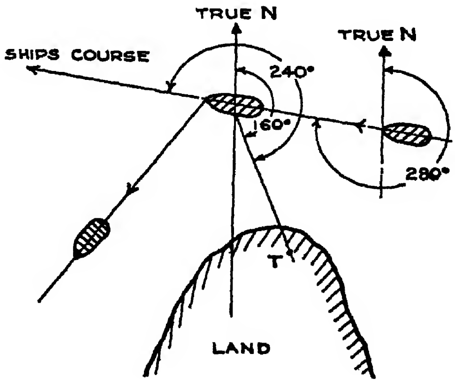


FIG. 133.

Thus, when W/T bearing + Q.E. on T is 85°, the ship can change course.

Again, the course may be altered when T lies 160° from true north. If the ship's course in this case is 280°, then—

$$\text{Bearing of station relative to true north} = \text{True ship's head} + \text{W/T bearing} + \text{Q.E.}$$
$$160 = 280 + \text{W/T bearing} + \text{Q.E.}$$

As the result would be negative, 360° must be added to the station bearing,

$$\text{i.e. } 520 = 280 + \text{W/T bearing} + \text{Q.E.}$$
$$\therefore \text{W/T bearing} + \text{Q.E.} = 240^\circ \text{ from ship's head.}$$

Thus, when the W/T bearing + Q.E. on T_1 is 240° from the ship's head, the ship can change course.

The Use of D.F. Installations to Avoid Collisions at Sea.—If in fog a ship A finds that W/T bearings on a ship B are at 0°, then there is a grave danger of collision. To avoid this, continuous watch should be kept on the D.F. set to note that—

(*a*) Position of B is not always 0°.
(*b*) Signal strength does not increase.

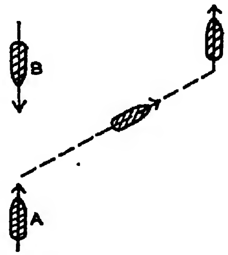


FIG. 134.

If watch is kept on the bearings, it is possible by taking a "sense" bearing to see whether the ship is drawing ahead or astern. In case of doubt, the course of B should be ascertained by a W/T call from A.

In danger of a collision, it is only necessary for A to change course so that B comes on the port bow, and when B has passed A can resume her normal course again.

An excellent method in fog would be for ships to be fitted with small power C.W. sets, say 10 watts, automatically sending out the call sign of the ship; wave-lengths, say, from 600 to 1000 m. being allocated to various ships. If these transmitters were allowed to run continuously, they would have no influence on normal traffic, and would be a very valuable asset to avoid collision in foggy weather.

Ships in Distress.—The quickest and safest method to succour a ship in distress is to get her to send frequently on her

W/T installation, and to steer so that her bearing is 0° from the ship. The position sent out by the vessel in distress is by no means reliable, and much more reliability can be placed on finding the vessel by using the D.F. apparatus.

Early in 1926 the "President Rooseveldt" was able to locate the sinking steamer "Antinoe" by this means.

CHAPTER IX.

HALF-CONVERGENCY.

W/T Bearings on Distances above 100 Miles.—In all previous examples, it has been assumed that the distance over which the bearing was taken was less than 100 miles. This assumption was made to avoid having to consider *half-convergency.*

W/T bearings on distances of over 100 miles will now be discussed.

The navigation is normally carried out on Mercator projection charts (see Chapter VII.). On these charts it is seen that great circles are in curves, while the rhumb lines are straight lines.

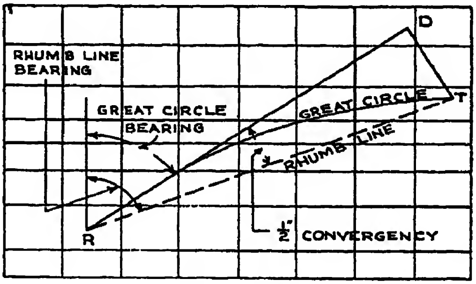


FIG. 135.

Consider Fig. 135 and the result of taking bearings at a long distance, say, 1000 miles.

T = transmitter. R = D.F. receiver.

Actually, the W/T wave travels along the great circle path TR. The apparent direction is, however, given by the tangent at R along the great circle, i.e. by the line RD. Thus the apparent position of T is at D, an error of about 4° at 1000 miles.

The angle DRT is equal to one-half the difference between the angles of intersection of the great circle with the meridians at R and T, and is called the *half-convergency.*

This half-convergency is dependent on :—

(*a*) *Direction of bearing.*
(*b*) *Difference in longitude between transmitter and receiver.*
(*c*) *Latitude.*

Bearings taken on stations which are north and south of one another, or approximately so, have little or no half-convergency correction.

Maximum half-convergency angles occur when the transmitting and receiving stations both lie in the same east and west lines. If both transmitting and receiving stations are situated near the equator, or if the mean latitude is the equator, then the half-convergency angle is very small.

Fig. 136 represents a typical case of bearings taken by great circle and rhumb line.

Angle NRG $= \alpha =$ Great circle bearing of T from R.
,, NRP $= \alpha' =$ Rhumb line bearing of T from R.
$\alpha' - \alpha = \psi =$ Half-convergency.

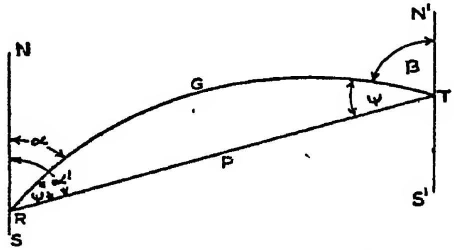


FIG. 136.—R = Receiver. T = Transmitter. RGT = Great circle bearing. RPT = Rhumb line bearing. NS and N′S′ = Meridians through R and T respectively.

There are various ways of calculating the value of the half-convergency angle, the accuracy of which is dependent on the distance between the transmitting and the receiving stations. This may be obtained from the difference of latitude between the transmitting and the receiving stations, and the difference in the longitude between the transmitting and the receiving stations.

The general formula for obtaining the half-convergency is—

$$\psi = \left\{ \begin{array}{l} \text{Half difference in longitude} \\ \text{between transmitter and} \\ \text{receiver} \end{array} \right\} \times \left\{ \begin{array}{l} \text{Sine mean latitude} \\ \text{between transmitter} \\ \text{and receiver.} \end{array} \right\}$$

For further details, see Appendix IV.

This half-convergency can be calculated out each time, but it is a tedious process. To avoid this, a scale such as shown in

Fig. 137 may be used. This scale was originated by Prof. Maurer. It represents differences for every 10′ of difference in longitude.

Example.—Let the mean latitude = 38·5°, and let difference in longitude = 145′.

For 38·5° the scale correction = 3·1′.

Then half-convergency correction $= \frac{145}{10} \times 3{\cdot}1' = 44{\cdot}95'$

$= 45'$ *approx.*

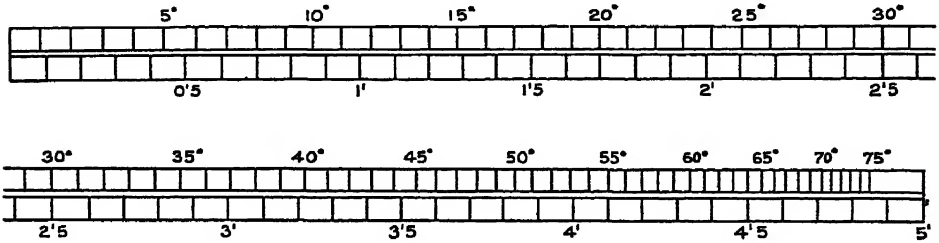


FIG. 137.

Prof. Maurer's Half-convergency Table.—A more accurate method of obtaining the half-convergency correction is to use the graph published by Prof. Maurer. This is given in Appendix II.

The use of this table is quite simple :—

L_1 = Latitude of receiver,
L_2 = Latitude of transmitter on which a bearing is taken.

From the table is read a correction factor k. This correction factor, multiplied by the difference in latitude between the two stations, gives the half-convergency correction.

Sign of Half-convergency.—One must decide whether to add or subtract this half-convergency relative to the bearing obtained. Whether the half-convergency must be added or subtracted is dependent on—

(1) Relative positions of the two stations on the earth's surface.
(2) Whether it is required to convert great circle bearings to rhumb line or *vice versa.*

The Great Circle is always concave to the equator.—Knowing this, we can find the sign of the half-convergency correction. Consider the following diagrams.

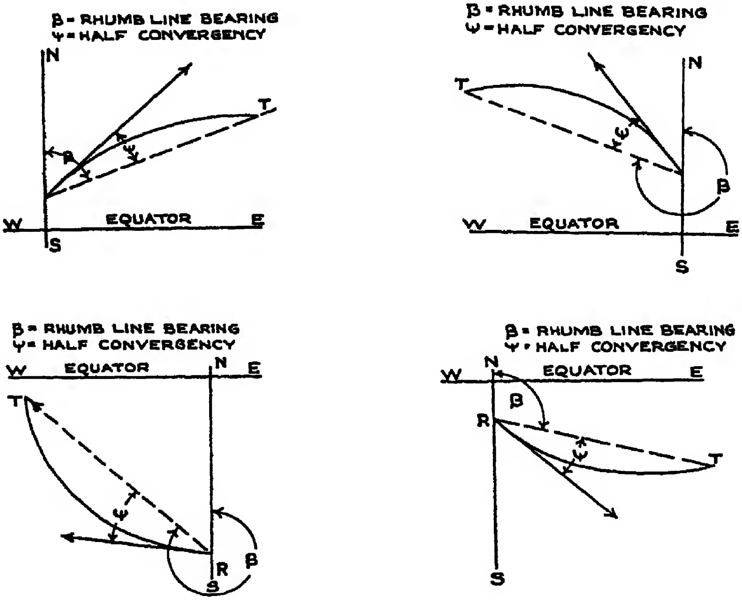


FIG. 138.

From an examination of the diagrams the following rules are obtained :—

Case.	Mean latitude.	Position of transmitting station	Given Rhumb Line, to convert to Great Circle	Given Great Circle, to convert to Rhumb Line
I.	North	W. of D.F.	Add	Subtract
II.	South	" "	Subtract	Add
III.	North	E. of D.F.	"	"
IV.	South	" "	Add	Subtract

All bearings should be expressed in degrees east of north (i.e. on 360° compass) before applying the half-convergency correction.

EXAMPLE OF THE APPLICATION OF THE HALF-CONVERGENCY CORRECTION TO A W/T BEARING.

Case I. Position Line from a W/T Bearing on One Station.—Suppose a bearing on the transmitting station T taken on the ship S gave 75°, i.e. after all corrections for deviation, variation, etc. (Fig. 139).

Now suppose a position line from the transmitting station T is drawn, and the half-convergency neglected, then the apparent (incorrect) position of the ship is S_1.

Correcting for half-convergency gives the true position S.

Case II. Position Lines from Two Stations (i.e. a Fix) applying Half-convergency.—Imagine W/T bearings taken from the ship S on the transmitting stations T_1 and T_2.

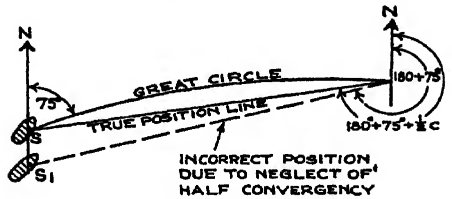


FIG. 139.

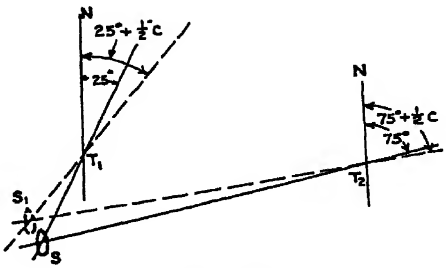


FIG. 140.

Let corrected bearing, i.e. converted to true north, be 25° on T_1 and 75° on T_2 (Fig. 140).

Neglecting the half-convergency corrections and laying off the position lines on T_1 and T_2, the ship's position is given at S, which is incorrect.

The distance between the false position and the true position will be dependent upon the accuracy with which the half-convergency correction is used, and the distance of the ship to the transmitting stations T_1 and T_2, even provided all other factors are absolutely accurate, i.e. W/T bearing positions of T_1 and T_2 on the chart, calculation of the ship's head from true north, and corrections for deviation, variation, etc.

Thus one sees that besides being a tedious process to orient a ship by two cross bearings, the accuracy at long distances, say over 500 miles, cannot be entirely relied upon, and the bearings on long distances should only be looked upon as useful checks to navigation.

CHAPTER X.

OTHER EFFECTS ON BEARINGS.

Effects of Neighbouring Aerials.—It is obvious that wherever the D.F. set is installed on the ship, the frame must be below the level of the ship's main aerial.

If the main aerial or, in the case of battleships, any auxiliary aerials, are tuned to or near to the wave-length of the station on which bearings are being taken, then the D.F. bearing will be hopelessly incorrect. Tests show that an aerial tuned to the same wave-length as that which is being received on the D.F. set will, even at 150-200 yds. from the frame, alter the bearings by 0·5°. Thus, although it is not possible to take a bearing on a ship and receive at the same time on another aerial on the ship, yet any passing ship which is more than 200 yds. distant, even when tuned to the wave-length being taken on the D.F. set, will not materially influence the bearing.

Provided, however, that the ship's receiving aerial is tuned to a wave-length differing from that being received on the D.F. set by a wave-length difference of more than 30 per cent., then the influence on the D.F. set is less than 0·5°. However, the safest and surest method to ensure that the D.F. bearings are not influenced by the ship's other aerials, is to arrange that while the D.F. bearing is being taken, all the ship's other aerials are broken and insulated. This is provided for in the ship's installation (see Chapter V.).

Coastal Refraction (Bad Bearing Angles).—It is well known that when a light wave travels from a medium of one density to another medium of a different density, there is an apparent bending of the light rays. This is termed refraction.

Imagine a light ray to travel through air to glass. The ray is bent from its original direction as shown in Fig. 141. On emerging from the glass (i.e. the medium of heavier density) to

the air (the medium of rarer density) the ray takes up its original direction.

Similarly, refraction occurs of wireless waves over sea and land. The velocity of waves over sea is at least 2 per cent. to 5 per cent. greater than over land. Thus there is apparent deflection of the wireless waves near the coast.

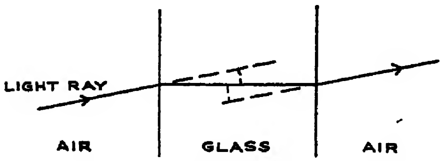


FIG. 141.

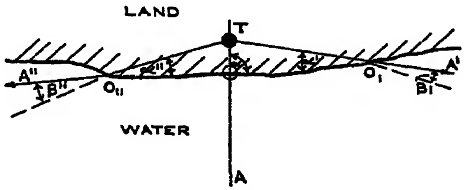


FIG. 142.

This is of special importance in taking a bearing at sea on a coast station, particularly if this station is situated somewhat inland.

Imagine conditions such as in Fig. 142.

Here is shown a condition where the waves from a transmitter T, lying at a distance inland, travel partly over land before travelling over the sea.

Imagine a receiver on a ship at A. Here the angle that the wave makes with the coast line is approximately 90°.

In this condition there is no refraction. At A′ there is a false bearing by an angle β', and at A″ by an angle β''.

The variation of this angle, due to coastal refraction, may best be expressed in the form of the accompanying graph.

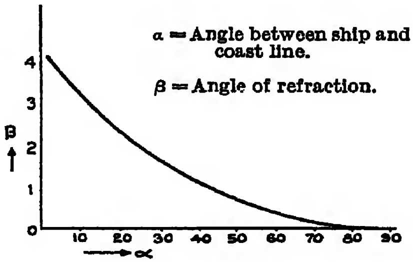


FIG. 143.

Thus, for really accurate D.F. work on coastal stations, the best arrangement would be for the transmitter to be placed on a lightship, so that there would be a homogeneous medium between the transmitter and receiver, and coastal refraction errors would only occur with bearings taken from points where the line joining the lightship and the D.F. receiver passed over projections from a broken coast line.

Bad Bearing Angles.—Experience over long periods, and results of numerous bearings, have shown that around certain coast stations there are definite regions in which bad bearings are always a possibility. In order to avoid the risk of uncertain bearings, maps have now been prepared of well-known W/T stations used largely on D.F. work showing definitely what areas are bad bearing angle areas.

An example is given in Fig. 144.

When a bearing is taken on a station in a region definitely known to be a position of bad angle bearing, the navigator should be informed of this and that the bearing can therefore only be taken as approximate.

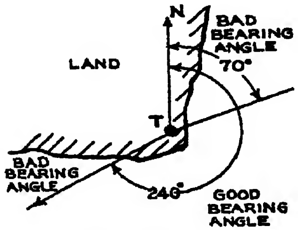


FIG. 144.

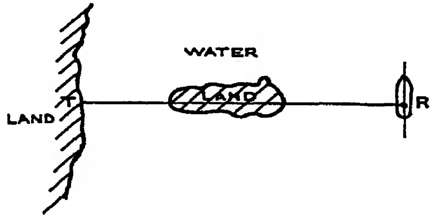


FIG. 145.

Errors due to Land Between Transmitter and Receiver.—It frequently occurs that bearings must be taken on a station situated as shown in Fig. 145.

Frequently bearings so taken are a few degrees out due to the refraction of the waves on the land masses.

In a series of tests conducted at Orford in January, 1920, it was noticed that while bearings on Flamborough and Berwick remained fairly constant both by day and night, i.e. the maximum deflection from the true bearing did not exceed 2°, the bearings on Malin Head, i.e. somewhat similar conditions to those in Fig. 145, varied as much as 3° by day and 7° by night from the true bearing position.

Night Effect.—Experience has shown that by day, i.e. during the period from one hour after sunrise to one hour before sunset, W/T bearings can be relied upon as a really valuable aid to navigation. The average error during the day does not as a rule exceed 0·5°, provided that bearings are taken under normal conditions, i.e. free from coastal refraction, bad angle conditions, and so on.

By night, however, this is by no means the case. The apparent bearings may be very inaccurate. To take a specific example: The bearing from Orford W/T on Lizard W/T by day was correct to 0·5°, but by night the error was consistently 7° to 9°.

Sometimes the wanderings of the bearings by night are exceptionally rapid, and it is quite possible for an experienced operator to follow them on a good D.F. set.

This wandering and changing of bearings by night is called *night effect*.

Influences on Night-effect.—It is dependent upon—

(1) The nature of the country over which the waves travel.
(2) The distance between the transmitting and the receiving stations.
(3) The wave-length used.
(4) The type of transmission, i.e. whether Spark, C.W., or I.C.W.

(*a*) The "night-effect" is more noticeable over land than over sea.

(*b*) Night effect commences at distances of about 20 miles, reaches a maximum at about 300 miles, and over very long distances is practically nil.

(*c*) With short waves (i.e. waves below 100 metres) the "night-effect" causes big deflections of bearings, and these deflections of bearings occur very rapidly.

Waves under 100 m., which will give very accurate bearings by day, are liable to such rapid changes by night that it is quite impossible to obtain even an approximate bearing.

With wave-lengths from 800 m. upwards, there is little difference in the deflection of the bearings due to "night-effect." The waves which are most influenced by "night-effect" are short, pure C.W.

(*d*) During the day the best bearings can be obtained on pure C.W. or I.C.W., while by night I.C.W. or Spark give less deflection. For working of D.F. throughout the twenty-four hours, I.C.W. gives the best results, and has the advantage that it may be very sharply tuned, and so does not jam other transmitting stations.

Observations in the hours of darkness on I.C.W. of 1000 m.

wave-length at distances of over 100 miles show maximum deflections $\pm$ 6° from the true bearing. By taking mean bearings this gives an error of $\pm$ 3°.

A typical example of "night-effect" on a bearing is given in the following curve.

The true bearing in the above example is 267°.

One sees that the bearings are liable to wander on either side of a mean reading; which wandering may be quick or slow, and, in any case, the minima are liable to grow "woolly."

If a mean is taken of the maximum and minimum readings, the error is not large.

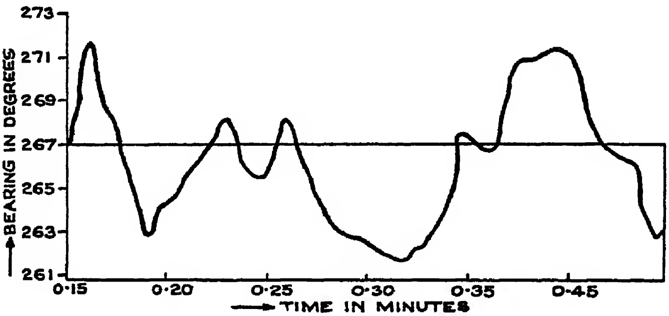


FIG. 146.

In the case of "night-effects," which are always easily recognisable by the wandering of the minimum and the value of the coupling between the frame and the vertical aerial over specific values either side of the mean value, it is recommended that as large a number of bearings be taken as possible, when the mean bearing will generally be very nearly correct.

It is noticeable that over long ranges "night effect" is not observed.

This has been investigated theoretically in a recent paper by T. L. Eckersley, who gives the following explanation of "night-effect."

Polarisation.—Imagine a source of vibrating electrons as in Fig. 147, such as a flame.

From such a source waves can be imagined to be emitted in every possible plane, i.e. if a sphere were drawn about the source, waves would be impinging on the spherical surface at every possible angle.

Suppose that all the vibrations emitted from our source were along a plane at right angles to the paper and along the line AB. Then these vibrations would be considered to be *polarised* along a *horizontal plane*.

If, on the other hand, the vibrations were in a plane at right angles to the paper and along the line CD, they would be *vertically polarised.*

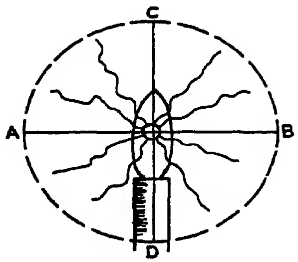


FIG. 147.

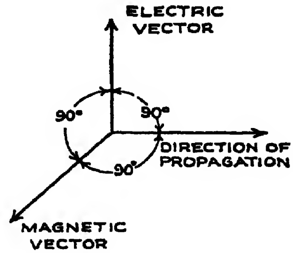


FIG. 148.

Now, in all wireless transmissions the following may be considered to represent the method of propagation of electric waves.

A wave-front has two vectors at right angles to the direction of propagation—the electric vector, which is polarised vertically; and the magnetic vector, which is polarised horizontally (Fig. 148).

Normally, the magnetic vector is parallel to the earth's surface, and the electric vector perpendicular to the earth's surface.

Consider Fig. 149 and imagine waves travelling from A to B. These, in normal conditions, would travel along two paths—

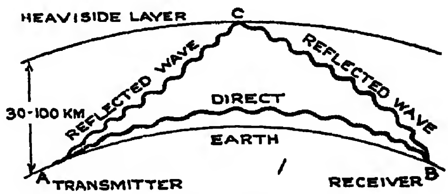


FIG. 149.

(1) *Direct path,* i.e. with the magnetic vector parallel to the earth's surface.

(2) *Reflected path,* i.e. with the magnetic vector not parallel to the earth's surface.

Theory of Night Effect.—Under normal conditions at a distance of 100-200 km. distance between A and B, as much energy from the reflected ray would reach B as from the direct way. The reflected ray makes an angle of something like 45°

with the earth's surface. Observations show that such high angle reflection is not present during the day-time, and the maximum angle is about 3° to 4°.

This phenomenon is explained by assuming that the layer acts as a good reflector for small angles of incidence and a very poor reflector for normal incidence. A layer of ill-defined under surface would act in this way.

A good method of differentiating between day and night bearings is to work on the following assumptions. Consider Fig. 150.

Day Transmission.—This is confined to the space between the earth's surface and the lower conducting layer. This layer may be considered as impervious to long wireless waves, i.e. to waves of the order of over 100 m.

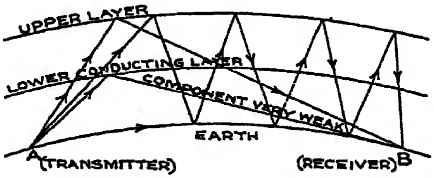


FIG. 150.

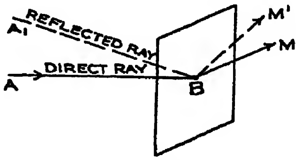


FIG. 151.

Night Transmission.—At night the ionising agent, i.e. the sun's γ (" Gamma ") rays, is removed and a recombination of ions causes the lower layer to disappear and the upper layer then comes into play.

This upper layer has a very much more defined under-surface than the lower layer, and can reflect wireless waves at much greater angles of incidence than those which exist in the daytime.

Consider a frame D.F. aerial at B.

By day the reception is chiefly due to the direct rays which have the electric vector polarised vertically and the magnetic vector horizontally.

The reflected rays, due to the absorption of the lower reflecting layer, do not exist to any appreciable extent. Consequently, relatively sharp bearings are obtained. The reflected rays do exist to a certain extent, but in insufficient strength to influence the bearings. Their effect is to cause the bearings to be less sharp. This can be shown by taking a frame which is

capable of rotation about a vertical axis and also capable of tilting about a horizontal axis.

On using a frame of this nature, a bearing can be obtained which may or may not be sharp when the frame is turned about the vertical axis. If the minimum of the bearing is broad, and if the bearing given by the vertical axis rotation is kept constant, and the frame turned about a horizontal axis, the minima can be made very much sharper. Moreover, on observations on constant transmitting stations, it has been noticed that when there have been large ionised thunder clouds between the transmitter and receiver, the bearings have shown a strong tendency to flatten and wander slightly. This is almost certainly due to the reflected ray being relatively strong in comparison with the direct ray. As soon as the clouds have passed, conditions have again become normal.

In general, however, it can be assumed that by day our reception is due almost solely to the direct ray.

By night, however, entirely different conditions arise. The upper reflecting layer is more pronounced, and besides the direct ray there exists a relatively strong reflected ray.

Imagine, as is shown in Fig. 151, that the direct ray is represented by AB with its magnetic vector polarised horizontally. Then, with the frame at B, perpendicular to the plane of the paper, there would be no signals.

If, however, a reflected ray A^1B is present, then BM^1 may be considered to be the direction of the magnetic vector, the electric vector being perpendicular to the plane of the paper.

Now, if an endeavour is made to receive signals at B, signals due to the component of the reflected ray A^1B are received.

The actual position of the minimum recorded by the frame will depend on :—

(1) The relative intensities of the direct ray AB and the reflected ray A^1B.

(2) The relative phases of the direct ray AB and the reflected ray A^1B.

The absolute maximum error would occur if the reflected ray were very strong relative to the direct ray and polarised so that the magnetic vector were vertical, and the electric vector horizontal.

Thus by day the result would be as shown in Fig. 152A, i.e. only the direct ray would be present, and by night a combination of the direct and reflected rays, as shown in Fig. 152B, would accrue.

Conditions for Presence of "Night-effect."—The conditions for distortion in bearings due to "night-effect" are :—

(1) That the reflected ray should make an appreciable angle with the earth's surface (i.e. high-angle reflection must be present).

(2) That there should be a component of the magnetic vector polarised in the vertical plane.

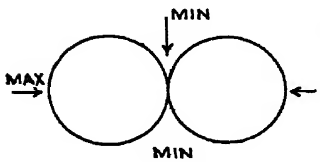


Fig. 152A.

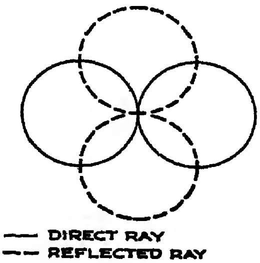


Fig. 152B.

If either of the above factors is absent, then no distortion is due to this cause.

In daytime—due to the ill-defined lower layer—high-angle reflection is not possible, and thus there is no distortion of bearings due to this cause.

Night-effect over Long Ranges.—Experimental evidence shows that for distances of 500 miles and over, "night-effect" is practically nil.

By reference to Fig. 150, and by assuming A and B to be, say, 1000 miles apart, the absence of night effect may be explained. At long ranges the direct ray only is received. This is due to the fact that the reflected ray is reflected a large number of times in travelling between the earth's surface and the upper reflecting layer. At each reflection this ray loses a certain percentage of energy, till at long distances its effect on the receiver is negligible, and consequently there is no distortion in the bearing.

The "woolly" nature of minima when "night-effect" is present is well known. This can be accounted for by the fact that the component due to the reflected ray is a variable and constantly changing quantity dependent upon the variation in height of the reflecting layer, and the angle of polarisation of the magnetic vector.

CHAPTER XI.

BEACON STATIONS, SOUND SIGNALLING AND ECHO-SOUNDING DEVICES.

General.—In the most critical time from the navigational point of view, i.e. in fog, most aids to navigation fail, e.g. lightships, beacon stations, lighthouses. Moreover, sound methods such as fog-horns are very uncertain and inaccurate aids to navigators in the case of fog. Even experienced navigators have been known to have judged wrongly the direction from which the sound came. In modern navigation, it becomes imperative to give the navigators as many accurate aids as possible. As wireless direction finding is independent of weather conditions, it offers an excellent method of assisting navigators. There are, however, some obvious drawbacks to this method :—

(1) It may not be possible to take bearings on a particular station or on particular stations owing to the fact that they are not working. Then it is possible that a number of ships will all want the particular shore station, especially in fog. This may possibly lead to chaos.

(2) Owing to jamming, it may not be possible to hear the desired W/T station.

(3) In order definitely to differentiate between any two stations transmitting in the normal way, a knowledge of Morse is essential. This means that D.F. will be in the hands of the W/T personnel, and the navigators, unless they possess a working knowledge of Morse, must be dependent on the W/T personnel for the accuracy of their bearings.

(4) No matter how accurate the wireless bearings may be

they can, at present, only give a definite direction, and unless it is possible to arrange a fix on two or more stations, or to work on a number of bearings on one station, it is not possible to estimate the distance between the transmitting station and the receiving direction finder.

The importance of the application of direction finding to navigation has been well investigated in recent years, and now special wireless beacon stations are established in U.S.A. in the congested waters going into New York, and a chain of W/T beacon stations is being laid down in Germany to assist in the navigation of ships making the Weser or the Elbe.

The principal American beacon stations are placed at Nantucket, Fire Island, and Ambrose Light-vessel.

The German wireless beacon stations at present working are at Borkum Riff, Norderney, and Elbe. Further stations are being erected at Amrum Bank and Weser.

Wireless beacon stations should be built with the following considerations :—

(1) They should be so arranged as to work as nearly continuously as possible. This eliminates (1) in the drawbacks to beacon stations.

(2) They should not be of too great a power to cause jamming, either of other ships working, or of one another. This means that if a spark system is used for transmission, it should be a system with a small damping. In view of modern research on wireless bearings and the comparative accuracies of bearings on spark, C.W., and modulated C.W. systems, it is highly probable that modulated C.W. is the best system to use.

(3) If these stations send a characteristic call, then they can be easily recognised after a little practice by anyone without the knowledge of Morse code. This eliminates (3) in the drawbacks to beacon stations.

Sound-signalling Apparatus (for Estimating Distance).—In order definitely to determine the distance of a ship from the beacon station, a system of sound signalling has been established on the Borkum Riff light vessel. This system is worked in conjunction with the D.F. gear as follows :—

Simultaneously with the W/T transmitter sending out twice its call sign, say — · · ·, the sound transmitter sends out its call sign of — · · ·. Also, the W/T transmitter follows its call sign with a series of dots. The time between each dot corresponds to the time taken for sound waves to travel a distance of 1 sea mile in sea water. The W/T signal can be taken as being heard instantaneously, while the sound signal takes a definite time to travel through the water. The person operating the D.F. and sound reception gear on the ship hears first the W/T signal, followed by a system of dots. He counts the dots until he hears the sound signal. The number of dots counted gives the distance in sea miles of the ship from the transmitter. This can be easily understood from Fig. 153, which shows the system of signals at, say, 10 miles.

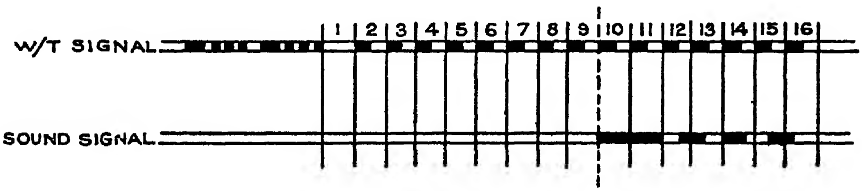


FIG. 153.

First the call sign is sent by each system, and then the dots sent by the W/T system are standardised to represent sea miles. All that the operator has to do on hearing the W/T signal is to count the dots until the sound signal is heard. This system of signalling is repeated by the beacon station seven times in $3\frac{1}{2}$ minutes. Thus the operator gets seven checks and takes a mean reading. This system works very satisfactorily up to distances of about 10-12 sea miles.

Depth-Sounding Apparatus.—An excellent method of ascertaining and confirming the position of a ship near the coast is by means of soundings and checking these soundings against those given on the chart. The soundings can be obtained by means of a lead line. In the past few years much better methods of taking soundings have been devised.

Behm Echo Depth Sounder.—One method, the Behm Echo Depth Sounder, is illustrated in Fig. 154.

A small cartridge rifle is fired from FH. The small shell fired detonates a few feet below the surface, producing a

powerful sound wave which through the microphone A starts a recording instrument in the chart room. The sound wave is reflected from the sea bed to microphone B. This has the reverse action to A and stops the time recorder. The recorder is calibrated in fathoms, and the distance travelled by the pointers on the chart room instrument is a direct reading of the depth of the sea bed. Several soundings can be taken in one minute if necessary.

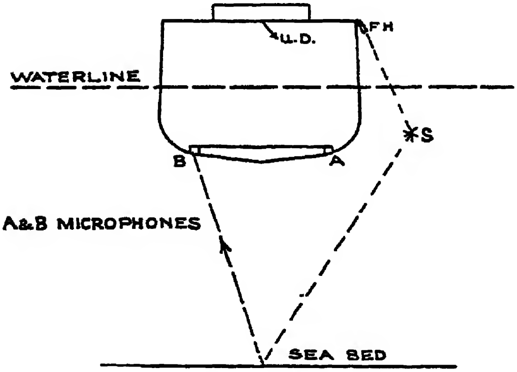


FIG. 154.

Admiralty Type Echo Sounder.—A second type of echo depth sounder is shown in Fig. 155. This type has been developed by the Admiralty Research Department.

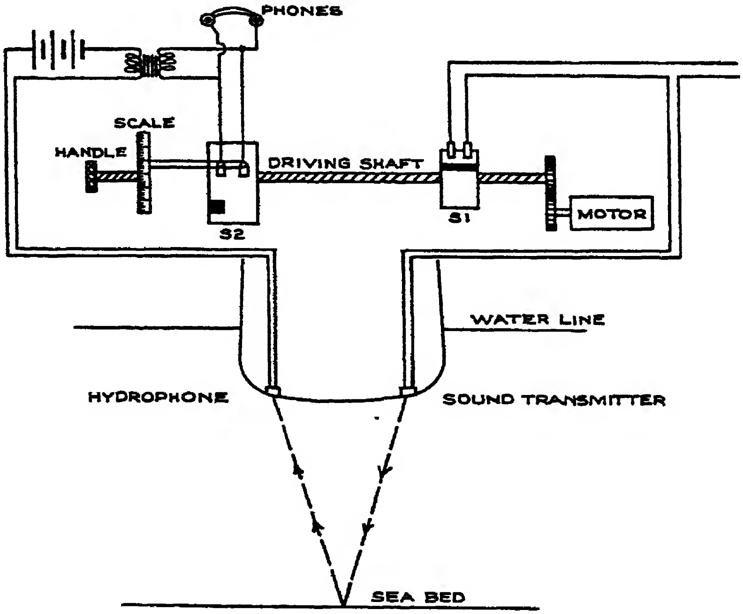


FIG. 155.

The transmitter creates a sound wave which is reflected from the sea bed and picked up by the hydrophone and heard in the telephones.

The whole apparatus is driven by a small motor ($\frac{1}{8}$ h.p.), and geared through a reduction gear of 10 : 1, which ensures a constant speed.

One rotary disc S_1 breaks the mains supply and actuates the transmitter. The second rotary disc S_2, running on the same driving shaft, short-circuits the telephones in the receiving circuit except as determined by the position relative to the corresponding pair of brushes of a second insulating segment.

When the apparatus is running no sound will, therefore, be heard in the telephones unless the insulating segment in the telephone switch S_2 happens to open the telephone circuit at the instant when the transmitter is actuated, or at the instant when the echo returns from the sea-bed.

In operation, the brushes on the telephone circuit rotating switch S_2 are displaced relatively to the corresponding brushes in the transmitter rotating disc S_1, so that an interval of time proportional to the angular displacement of the brushes intervenes between the starting of an impulse from the transmitter and the opening of the telephone circuit. If now a sound is heard in the telephones, the angular displacement of the brushes, in terms of the known speed of rotation of the switch, gives a measure of the time taken for the sound to travel from the transmitter to the sea-bed and return to the receiver, i.e. approximately twice the depth of water.

Thus in this apparatus the actual sounding is read directly on the scale, and no calculations are necessary.

There are two types of this gear, one for shallow water soundings and the other for deep water sounding, with a maximum range of 4000 fathoms. These instruments are made by Henry Hughes & Sons of London.

The Fathometer.—Another method of determining the sounding of a ship consists of a piece of apparatus manufactured by the Submarine Signal Corporation of Boston, Massachusetts, called the "Fathometer." This instrument is based on the principle of emitting a sound wave from a sound transmitter, causing this wave to be reflected from the sea-bed, and receiving the reflected sound wave on a receiver. The

interval of time between the emission of the sound and reception of the sound is measured by a special device.

The apparatus consists essentially of three parts :—

(a) A sound transmitter (oscillator) riveted to the outer shell of the ship.

(b) A sound receiver (hydrophone) in a small tank which is mounted on the inner surface of the shell of the ship.

(c) A fathometer which controls the sound emissions, receives the electrical impulses due to the echo of the sound wave from the sea-bed, and translates the time interval between the transmission and reception of the sound into an indication of depth.

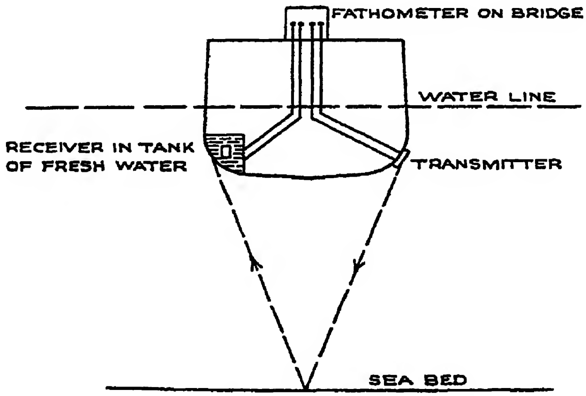


Fig. 156.

Diagrammatically, the fathometer may be shown as in Fig. 156.

The instruments are considerably magnified. The transmitter is actually about 12 ins. in diameter and 4 ins. deep, while the fathometer is about 13 ins. square. The receiver is of the ordinary telephone microphone type. The oscillator, which sends out enormous sound energy in a very small space of time at a frequency of 1050 cycles per second, is operated electro magnetically, using alternating current supply.

In the circuit between the hydrophone and the fathometer a filter circuit is arranged in conjunction with a thermionic valve amplifier, so as to eliminate all extraneous noises such as the motion of the ship through the water.

For depths up to 100 fathoms the sound energy reflected on to the hydrophone is caused to actuate a relay which in turn actuates the fathometer.

In depths of over 100 fathoms, the sound energy reflected on to the hydrophone actuates a pair of head receivers, and the note of the transmitter is heard in the telephone.

The fathometer consists of a rotating disc which is driven at a constant speed by a small motor. In front of the disc are two scales, 0-600 fathoms and 0-100 fathoms. The disc makes four revolutions per second when measuring depths of less than 100 fathoms, and one revolution in 1·5 seconds when used for measuring depths greater than 100 fathoms.

The general principle of the working of the instrument in shallow water, i.e. to 100 fathoms depth, is as follows:—An electric circuit is closed which causes the sound transmitter to send out a powerful sound wave to the sea-bed. Simultaneously with the emission of this sound wave an electric discharge is sent through a Geissler tube giving a flash of light, and indicating that a sound wave has been transmitted. The sound wave is reflected from the sea-bed, and the echo acting on the hydrophone causes a relay to close which gives a second luminous discharge through the Geissler tube, which by this time has travelled a certain distance around the scale. This second flash acts as a luminous indicator, and if, for example, one-eighth second has elapsed between the emission of the sound wave and the return of the echo, the Geissler tube will have travelled one-half the distance around the scale, and the flash will be opposite the 50 fathoms mark, showing that the depth is 50 fathoms.

As the flashes follow one another in very rapid succession, the Geissler tube gives practically a continuous pencil of light as an indicator. For distances greater than 100 fathoms, a white incandescent lamp lighted from a low-voltage battery is used as an indicator instead of the Geissler tube. As before, the transmitter circuit is closed when the light is opposite the zero on the scale. The echo from the sea-bed produces a musical note in the phones. The position of the white light on the scale indicates the depth indirectly on the scale.

The instrument is very robust, automatic, and exceptionally simple to work.

Summary.—We therefore have three definite methods other than actual visual methods, for helping to orient a ship's position, and all these methods are independent of fog. These are :—

(1) Bearings relative to known transmitting stations using wireless direction finder instruments.

(2) Sound methods giving distance from known transmitting stations.

(3) Echo depth sounding apparatus.

In modern navigation all accurate methods by which the ship's position can be ascertained are of immense help, especially in times of fog. It is strongly advised that all methods should be used as frequently as possible, so that everyone becomes familiar with the various types of apparatus and confidence is established in the gear. Then, when an emergency arises, everyone responsible for the ship's navigation knows exactly the reliance that can be placed on the ship's position.

APPENDIX I.

CARE AND MAINTENANCE OF ACCUMULATORS.

Usually manufacturers of accumulators supply printed instructions with all their batteries. These instructions should be carefully adhered to in order to get the best results and the longest life out of the batteries.

The following rules apply generally to all lead accumulators :—

First Charge.—This should commence immediately after adding the acid, and should last 36-40 hours. The first 12 hours *must* be continuous charging. The specific gravity of the acid rises on charging, and should it rise above 1210, add pure distilled water to reduce the specific gravity to 1205-1208.

Rate of Charging.—This will be given on the cell containers, and should be adhered to. Charging should be done as soon as possible after discharging.

Rate of Discharging.—This is given on the cells, and the maximum discharge rate should not be exceeded.

Level of Electrolyte.—The acid must never be allowed to fall below half an inch above the top of the plates, i.e. the plates must be kept well covered. Any loss due to evaporation should be made good by adding pure distilled water at the end of the charge.

Testing.—All cells should be examined and tested once per week, using a voltmeter for testing. The E.M.F. per cell should never be allowed to fall below 1·8 volts. Any cell lower than 1·8 volts should be charged up and examined for internal contacts between plates. Any sediment should be removed.

Specific Gravity.—The specific gravity of fully charged cells should be between 1205-1210 at 60° F. Allow 1° sepecific gravity fall for every 3° Fahrenheit rise, i.e. specific gravity, 1205 at 60° equals 1202 at 69° F. and 1208 at 51° F. If the specific gravity rises above 1210, reduce by adding pure distilled water after the end of a charge whilst the plates are gassing.

Polarity while Charging.—Care must be taken in charging that the positive of the charging circuit is connected to the positive of the battery. The cells should be cut out of circuit before the charging generator is shut down.

Completion of Charge.—Cells can be considered charged when they have been gassing freely from both plates for about one hour, and the voltage per cell is 2·2 volts.

Idle Cells.—If it is required to leave cells out of action for any length of time the acid must not be removed, but the battery should be previously fully charged and care taken that the plates are fully covered with electrolyte. Efforts should be made to charge these idle cells about once per fortnight. The charge should be continued until the cells gas freely.

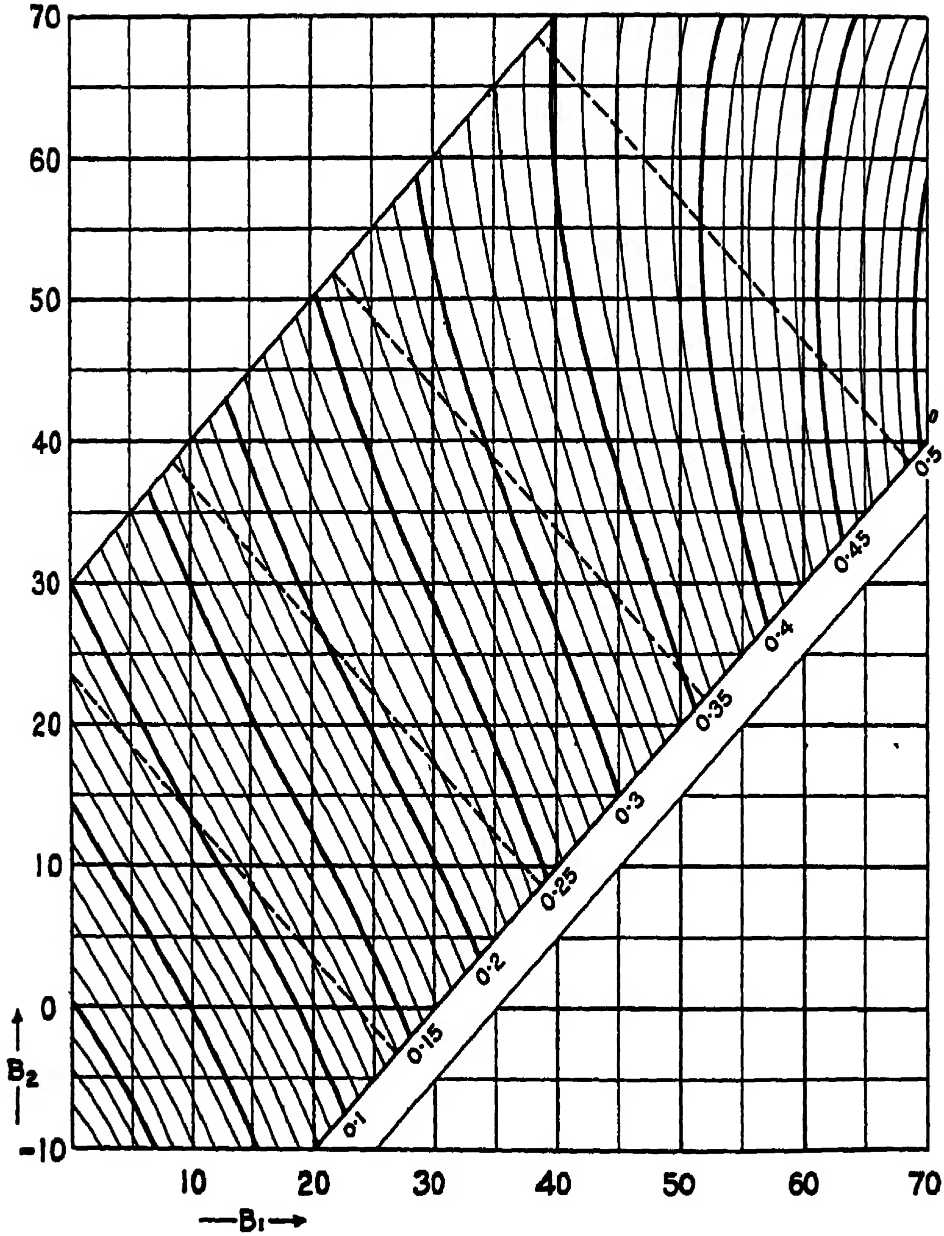


FIG. 157.

[*To face page* 155.

APPENDIX II.

USE OF PROF. MAURER'S GRAPHICAL TABLE.

This table is so arranged that for every combination of the latitude of the D.F. set (B_1) and the latitude of the transmitting station (B_2), there is a definite correction factor k. This correction factor multiplied by the difference in latitude between the D.F. set (B_1) and the transmitting station (B_2), gives the half-convergency angle required.

The abscissæ B_1 represent the latitude of the D.F. set (B_1).

The ordinates B_2 represent the latitude of the transmitting station (B_2).

The correction factor k is given in the table.

Then half-convergency $= (B_1 - B_2) \times k$ in degrees.

Example I.—Suppose the latitude of the D.F. receiver $(B_1) = 45°$. Suppose the latitude of the transmitting station $(B_2) = 25°$. From the table for $B_1 = 45°$ and $B_2 = 25°$, $k = 0{\cdot}325$.

$$\begin{aligned}\text{Then half-convergency in degrees} &= (B_1 - B_2)k \\ &= (45 - 25) \times 0{\cdot}325 \\ &= 20 \times 0{\cdot}325 \\ &= \underline{6{\cdot}5°}.\end{aligned}$$

The sign of the half-convergency is determined as shown on page 134.

Example II.—Let latitude of D.F. receiver $= 22°$, i.e. B_1. Let latitude of D.F. transmitting station $= 12°$, i.e. B_2. From table for $B_1 = 22°$ and $B_2 = 12°$, $k = 0{\cdot}16$.

$$\begin{aligned}\text{The half-convergency in degrees} &= (B_1 - B_2)k \\ &= 10 \times 0{\cdot}16 \\ &= \underline{1{\cdot}6°}.\end{aligned}$$

APPENDIX III.

TRIGONOMETRICAL RATIOS.

In the right-angled triangle POM the following definitions are employed with reference to the angle O :—

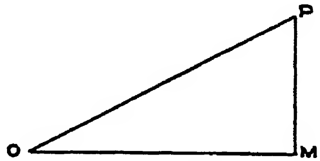


FIG. 158.

The ratio $\frac{PM}{OP}$ or $\frac{\text{opposite side}}{\text{hypotenuse}}$ is called the sine of O, i.e. $\frac{PM}{OP} = \sin O$.

" " $\frac{OM}{OP}$ or $\frac{\text{adjacent side}}{\text{hypotenuse}}$ " " the cosine of O, i.e. $\frac{OM}{OP} = \cos O$.

" " $\frac{PM}{OM}$ or $\frac{\text{opposite side}}{\text{adjacent side}}$ " " the tangent of O, i.e. $\frac{PM}{OM} = \tan O$.

" " $\frac{OM}{PM}$ or $\frac{\text{adjacent side}}{\text{opposite side}}$ " " the co-tangent of O, i.e. $\frac{OM}{PM} = \cot O$.

" " $\frac{OP}{OM}$ or $\frac{\text{hypotenuse}}{\text{adjacent side}}$ " " the secant of O, i.e. $\frac{OP}{OM} = \sec O$.

" " $\frac{OP}{PM}$ or $\frac{\text{hypotenuse}}{\text{opposite side}}$ " " the cosecant of O, i.e. $\frac{OP}{PM} = \text{cosec } O$.

That is,

$$\cot O = \frac{1}{\tan O}.$$

$$\sec O = \frac{1}{\cos O}.$$

$$\text{cosec } O = \frac{1}{\sin O}.$$

The above six ratios are known as the trigonometrical ratios, and are constant as long as the angle remains the same.

APPENDIX IV.

Consider Fig. 159.

Then—

$$\alpha + \psi + \beta + \psi = 180°.$$
$$2\psi + \alpha + \beta = 180°.$$
$$\psi + \tfrac{1}{2}(\alpha + \beta) = 90°.$$
$$\psi = 90° - \tfrac{1}{2}(\alpha + \beta).$$
$$\cot \psi = \cot [90° - \tfrac{1}{2}(\alpha + \beta)].$$
$$= \tan \tfrac{1}{2}(\alpha + \beta).$$

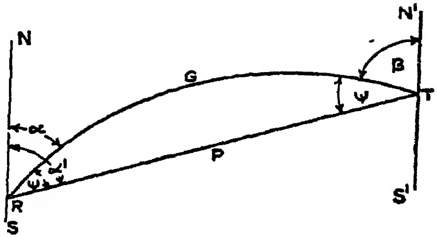


FIG. 159.—R = Receiver. T = Transmitter. RGT = Great circle bearing. RPT = Rhumb line bearing. NS and N'S' = Meridians through R and T respectively.

The value for tan ½ $(\alpha + \beta)$ is given in Napier's Analogy Tables for calculating the great circles between two known places, and is expressed by the formula—

$$\tan \tfrac{1}{2}(\alpha + \beta) = \cot \frac{\gamma}{2} \cos \tfrac{1}{2}(\alpha - \beta) \sec \tfrac{1}{2}(\alpha + \beta).$$

This can be seen by considering the spherical triangle in Fig. 160.

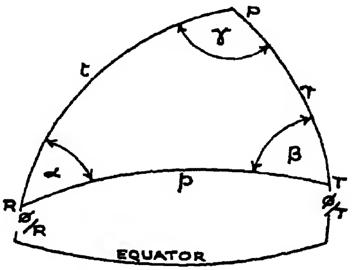


FIG. 160.

R = Receiver. T = Transmitter. P = Pole. $r = \left(90° - \frac{\phi}{T}\right) =$ (complement of latitude from place T). $t = \left(90° - \frac{\phi}{R}\right) =$ (complement of latitude from place R). p = Distance between receiver and transmitter. α = Receiver angle to meridian. β = Transmitter angle to meridian. γ = Difference in longitude between receiver and transmitter.

Since $$r = 90° - \frac{\phi}{T},$$

and $$t = 90° - \frac{\phi}{R}.$$

Then
$$r + t = \left(90° - \frac{\phi}{T}\right) + \left(90° - \frac{\phi}{R}\right)$$
$$= 180° - \left(\frac{\phi}{T} + \frac{\phi}{R}\right).$$
$$\tfrac{1}{2}(r + t) = 90° - \tfrac{1}{2}\left(\frac{\phi}{T} + \frac{\phi}{R}\right)$$
$$= 90° - \phi_m.$$

Where m = mean latitude between transmitter and receiver, also—
$$r - t = \left(90° - \frac{\phi}{T}\right) - \left(90° - \frac{\phi}{R}\right).$$
$$r - t = \left(\frac{\phi}{R} - \frac{\phi}{T}\right).$$
$$\tfrac{1}{2}(r - t) = \tfrac{1}{2}\left(\frac{\phi}{R} - \frac{\phi}{T}\right).$$

Substituting this value in the Napier Analogy Tables, then
$$\tan \tfrac{1}{2}(\alpha + \beta) = \cot . \psi = \cot \frac{\gamma}{2} \cos \tfrac{1}{2}\left(\frac{\phi}{R} - \frac{\phi}{T}\right) \sec (90° - \phi_m).$$

For short distances between R and T,
$$\cos \tfrac{1}{2}\left(\frac{\phi}{R} - \frac{\phi}{T}\right) = 1 \text{ (approximately)}.$$

Also,
$$\operatorname{cosec} \phi_m = \sec (90° - \phi_m).$$

Thus—
$$\cot \psi = \cot \frac{\gamma}{2} \operatorname{cosec} \phi_m,$$

i.e.
$$\tan \psi = \tan \frac{\gamma}{2} \sin \phi_m.$$

Also, as the tangent of small angles equals the value of the angle, this gives
$$\psi = \frac{\gamma}{2} \sin \phi_m,$$

i.e. half-convergency = $\frac{1}{2}$ diff. in longitude $\times$ sine mean latitude.

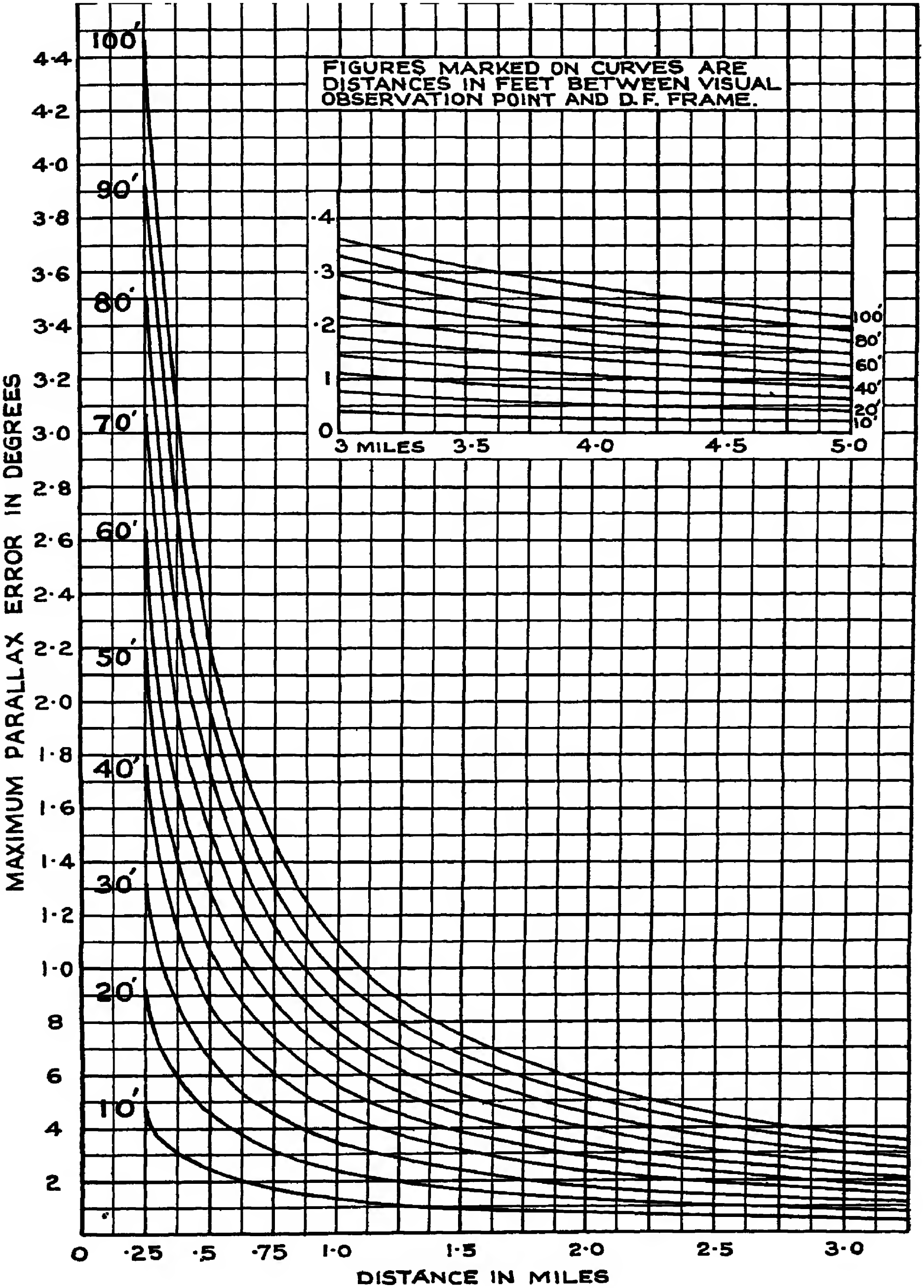


FIG. 161.—Maximum parallax error curves for distances between visual observation point and D.F. frame up to 100 feet.

[*See page* 159.

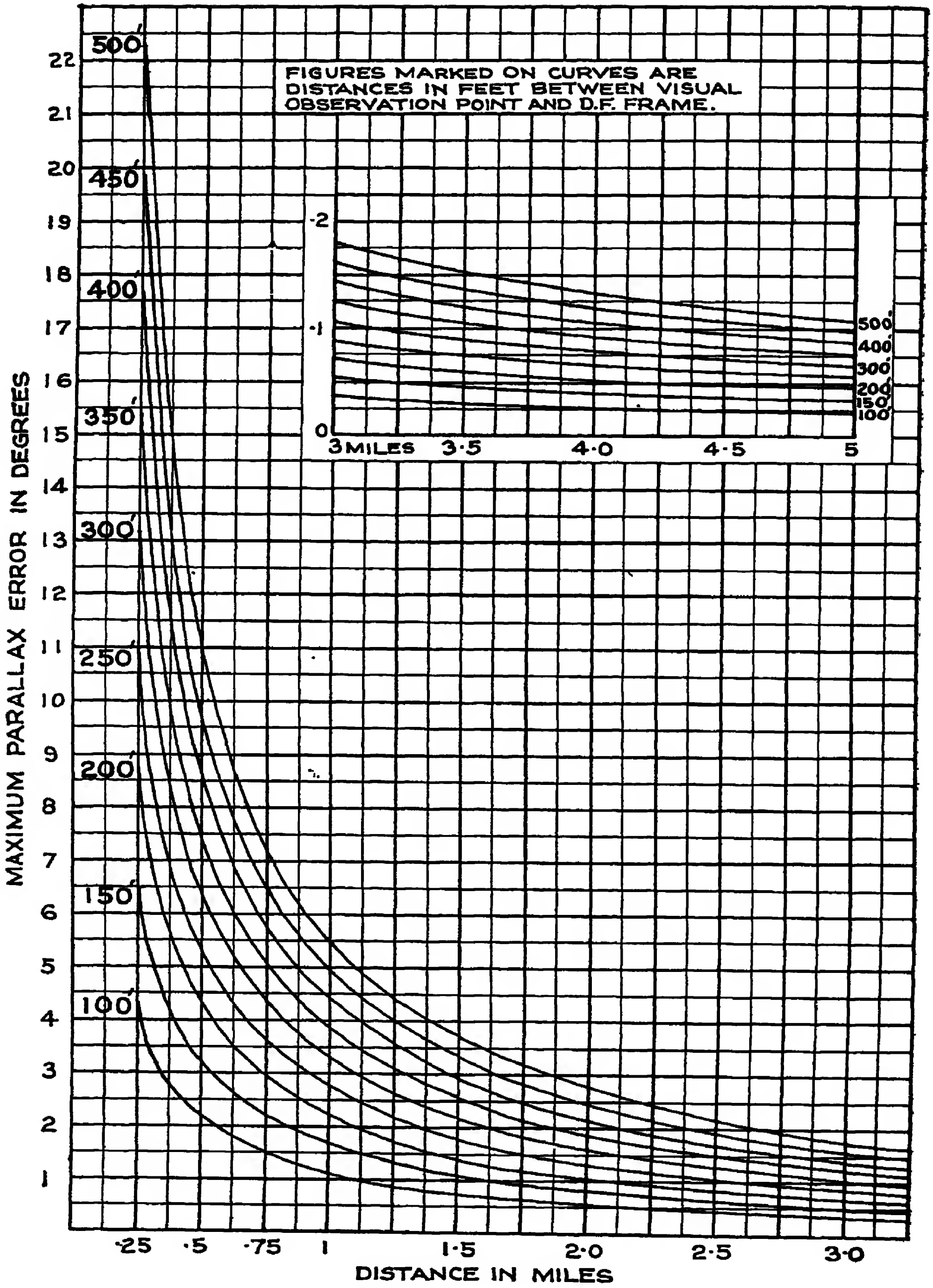


FIG. 162.—Maximum parallax error curves for distances between visual observation point and D.F. frame up to 500 feet.

[To face page 159.

APPENDIX V.

It has been shown in Chapter VI., page 102, that the parallax error varies relative to the fore and aft line of the ship, i.e. along the fore and aft line the error is nil. From dead ahead to starboard the error is negative, with a maximum at right angles to the base line joining the visual observation point to the D.F. frame. From dead astern to port the error is positive, with a maximum at right angles to the base line joining the visual observation point to the D.F. frame. This error varies according to—

(1) Base line, i.e. the distance between the visual observation point and the D.F. frame position.
(2) The distance between the ship and the observed object.

The parallax error increases as (1) increases, and as (2) decreases, i.e. a maximum parallax error occurs on a long base line, when observations are made on a near object. The attached curves give a rapid method of quickly finding the *maximum* parallax error for various base lines for distances up to 5 miles.

These errors are worked out for base lines of 10, 20, 30 . . . 100 ft., and 150, 200, 250 . . . 500 ft. for all distances from ½ mile to 5 miles,

It must be noted that the curves show the *maximum* parallax error, and from this the values at various angles from 0° to 360° can be calculated.

THE GREEK ALPHABET.

α	alpha	ι	iota	ρ	rho
β	beta	κ	kappa	σ	sigma
γ	gamma	λ	lambda	τ	tau
δ	delta	μ	mu	υ	upsilon
ϵ	epsilon	ν	nu	ϕ	phi
ζ	zeta	ξ	xi	χ	chi
η	eta	o	omicron	ψ	psi
θ	theta	π	pi	ω	omega

INDEX.

D

E

F

G

H

I

R

S

T

V

W

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